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Development of a Consumption-based Environmental Performance Index

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- uttak av masteroppgave

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Oppgavetekst/Problembeskrivelse

This master thesis will develop a consumption based index guided by the composition of the EPI. Based on this new index, the student will analyse the environmental performance of countries over time.

I. Reconstruct, as far as possible, the 2014 EPI index based on the provided background data from the official repository and derive the used weighting and summation algorithms.
II. Propose a consumption based environmental performance index guided by the composition of the EPI, taking into account the availability of consumption based footprint indicators time series. Investigate the differences between the proposed index and the current EPI.
III. Calculate the new consumption based index over time and compare to a corresponding index based on production based accounts over the available time series. Analyse and discuss the differences between the different accounting schemes.
IV. Investigate any signs of decoupling between economic development (as by household income or GDP) and the time series of the consumption and production based index. Based on the results, make a recommendation which index should be used for this kind of analysis.

Hovedveileder ved institutt **Seniorforsker Richard Wood**	Medveileder(e) ved institutt **Konstantin Stadler**
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4. Underskrift

Student: Jeg erklærer herved at jeg har satt meg inn i gjeldende bestemmelser for mastergradsstudiet og at jeg oppfyller kravene for adgang til å påbegynne oppgaven, herunder eventuelle praksiskrav.

Partene er gjort kjent med avtalens vilkår, samt kapitlene i studiehåndboken om generelle regler og aktuell studieplan for masterstudiet.

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PREFACE

This thesis was written over the fall of 2016 with a basis in the project work conducted in the fall of 2015. It investigates the 2014 Environmental Performance Index in relation to creating a consumption-based index intended for enhanced sustainability assessment.

I would like to extend my gratitude towards my two supervisors for helping me through this process; Konstantin Stadler for his regular follow up over the course of the fall of 2016, and Richard Wood for his invaluable feedback towards the finalization in January of 2017. This thesis marks the last chapter of a long educational journey, and I would like to thank my mother who has helped me throughout this process, and whose support I can always depend on. I would also like to thank my friends, and especially Karoline Veum Solberg for her moral support and advice towards the finalization.

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ABSTRACT

Exceeding pressure is put on the Earth’s ecosystems through increased consumption and human activities. Maintaining a sustainable level of resource use and keeping environmental impacts within acceptable limits is one of the greatest challenges of today. Several efforts have been made to quantify sustainability (e.g. the United Nations Millennium Goals (MDGs)) and measure environmental impacts. Setting specific targets for sustainability is an important part of promoting sustainable policy making. However, the traditional method used for these quantifications are based on a territorial (production-based) accounting (PBA) scheme, and impacts embodied in trade are not accounted for. An alternative accounting scheme using consumption-based accounts (CBA), or footprinting, can be applied to correct this problem through the use of Environmentally Extended multiregional input-output (EE MRIO) analysis.

This thesis combines the production-based 2014 Environmental Performance Index (EPI) with the EE-MRIO database EXIOBASE v3 to create an alternative consumption-based index. By incorporating CBA data into the EPI index an improved tool for sustainable decision-making may be achieved. The alternative index’s applicability in sustainability assessment is evaluated by comparing the original EPI and the alternative index. First the reproducibility of the EPI is examined. The two aforementioned indices are then investigated in detail for the year 2011 and furthermore a timeline comparison is conducted between 2002 and 2011 using China, Norway and the United States as example countries.

The EPI showed an appropriate level of reproducibility, both for the score values and for the weightings. Despite less reproducibility between data sources and raw data, the index methodology was deemed fit for further modification. For 2011, the results show significant methodological difference between the EPI and the alternative index compared to the differences from using different accounting schemes. The timeline results for three countries show trends in correspondence with the expectations for the relationship between production and consumption based accounting schemes from other research. However, the alternative indicators only amount to 37 % of the total index resulting in lowered influence on the final index. The alternative *CO_2 Intensity* indicator was compared to the greenhouse gas (GHG) impact results of the EXIOBASE v3 for the three countries over time. Points of similarity were found, but Norway stood out with a noticeably different curve likely caused by its net export of materials embodied in trade. Signs of absolute decoupling were detectible for all three countries.

The alternative index is suffering from the methodological differences observed, but still shows promising signs of accurately depicting the effects of switching accounting schemes (PBA to CBA). Improvements to the weightings and targets are necessary for the alternative index to provide a good alternative to the current EPI. If these adjustments are achieved however, such a consumption-based index could provide policymakers with an improved tool for decision-making, and thus contributing to a sustainable future with continued decoupling of environmental impacts from the economic development.

It is recommended to continue the development of the alternative index with a focus on targets and weightings in order to provide a robust consumption-based index that can be considered as a realistic alternative to the EPI.

SAMMENDRAG

Økende press blir satt på jordens økosystemer gjennom økt forbruk og menneskelige aktiviteter. Å opprettholde et bærekraftig nivå av ressursbruk og samtidig holde miljøkonsekvenser innenfor akseptable grenser er en av nåtidens største utfordringer. Flere forsøk har vært gjort for å kvantifisere bærekraftighet (f.eks. FNs tusenårsmål (MDG)) og for å måle miljøpåvirkninger. Setting av konkrete mål for bærekraftig utvikling er en viktig del av å fremme en bærekraftig politikk. Imidlertid er den tradisjonelle metoden som brukes for kvantifisering basert på en territorial (produksjonsbasert) regnskapsmetode (PBA), og konsekvensene av miljøpåvirkninger medført av handelen er ikke gjort rede for. En alternativ beregningsmetode som bruker forbruksbasert allokering (CBA), eller fotavtrykk, kan brukes til å løse dette problemet gjennom bruk av miljøutvidede flerregionale input-output (Environmentally Extended multiregional input-output (EE MRIO)) analyse.

Denne oppgaven kombinerer 2014 Environmental Performance Index (EPI), som er basert på territorielle regnskap, med en EE-MRIO database kalt EXIOBASE v3 for å utvikle en alternativ forbruksbasert indeks. Innlemming av CBA-dataene i EPI indeksen kan gi et forbedret verktøy i beslutningsprosesser for bærekraftig utvikling. Evalueringen av den alternative indeksens anvendbarhet i bærekraftighetsvurderinger er basert på sammenligninger mellom den opprinnelige EPI indeksen og den alternative indeksen. Først be reproduserbarheten av EPI undersøkt. Indeksene ble deretter undersøkt i detalj for året 2011, i tillegg til en sammenligning over tid mellom 2002 og 2011 ved hjelp av Kina, Norge og USA som eksempel land.

EPI viste et passende nivå av reproduserbarhet, både for poengverdier og for vektingene. Til tross for mindre reproduserbarhet mellom datakilder og rådata, ble indeksens metodikk ansett som egnet for videre modifisering. For 2011 viser resultatene betydelig metodisk forskjell mellom EPI og den alternative indeksen sammenliknet med de observerte forskjellene mellom de ulike regnskapsmetodene. Tidslinjeresultatene for de tre landene viser trender i korrespondanse med forventninger til forholdet mellom produksjon og forbruksallokering funnet i annen forskning. Imidlertid utgjør de alternative indikatorene kun 37% av den totale indeks vektingen, noe som resulterer i lavere innflytelse på den endelige indeksen. *CO_2 Intensity* indikatoren fra den alternative indeksen ble sammenlignet med funn for drivhusgass (GHG) påvirkninger fra EXIOBASE v3 for de tre landene over tid. Likhetspunkter ble funnet, men Norge hadde en ganske annerledes kurve enn de to andre landene, noe som sannsynligvis er forårsaket av den netto eksporten av materialer. Tegn på absolutt frakobling var synlig for alle de tre landene.

Den alternative indeksen lider av de metodiske forskjellene som ble observert, men likevel viser den lovende tegn på korrekt framvisning av effekten ved å bytte regnskapsmetode (PBA til CBA). Forbedringer av vektinger og mål er nødvendig for at den alternative indeksen skal kunne gi et godt alternativ til dagens EPI. Hvis disse justeringene oppnås kan den imidlertid gi politikere et forbedret verktøy for beslutningstaking, og dermed bidra til en bærekraftig fremtid med fortsatt frakobling av miljøpåvirkninger fra økonomisk utvikling. Det anbefales å fortsette utviklingen av den alternative indeksen med fokus på mål og vekter for å gi en robust forbruksbasert indeks som kan anses som et realistisk alternativ til EPI.

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ABBREVIATIONS

MRIO variables:

A – Interindustrial requirements matrix

F – Total impacts

L – Leontief inverse

S – Environmental extensions

x – Total output

y – Final demand

Other abbreviations:

AZE - Alliance for Zero Extinction

BGS – British Geological Survey

CBA - Consumption-based accounting

CBD - Convention on Biological Diversity

COP - Conference of Parties

CSD - United Nations Commission on Sustainable Development Framework

CIESIN - Center for International Earth Science Information Network

EEA - European Environmental Agency

EE MRIO - Environmentally Extended Multiregional Input-Output Analysis

EEZ - Exclusive Economic Zone

EPI - Environmental Performance Index

ESI - Environmental Sustainability Index

EU – European Union

FAO - Food and Agriculture Organization of the United Nations

FRA - Forest Resource Assessment

GDP - Gross Domestic Product

GHG - Greenhouse Gas

GNI - Gross National Income

GRI - Global Reporting Initiative

HDI – Human Development Index

HPB - High performance benchmark

ICES - International Council for the Exploration of the Seas

ICP - International Comparison Program

IEA - International Energy Agency

IGO - Intergovernmental Organization

ILO - International Labour Organization

IMF – International Monetary Fund

IOA - Input-Output Analysis

IRP – International Resource Panel

JMP - Joint Monitoring Programme for Water Supply and Sanitation

LCA - Life Cycle Assessment

LDC - Least Developed County

LPB - Low performance benchmark

MDG - Millennium Development Goals

MR EE SUT/IOT - Multi-Regional Environmentally Extended Supply and Use Tables / Input-Output tables

MRIO - Multiregional Input-Output Analysis

NAFO - Northwest Atlantic Fisheries Organization

OECD - Organization for Economic Cooperation and Development

PBA - Production-Based Accounting

PM2.5 - Fine particulate matter, particulates with a diameter of 2.5 microns and smaller.

POP - Persistent Organic Pollutants

PPP - Purchaser Power Parity

PSR - Pressure-State-Response

RoW - Rest of World

SDG - Sustainable Development Goal

SEEA - System of Environmental Economic Accounting

SIDS - Small Island Developing States

SNA - System of National Accounts

SUT – Supply and Use Table

UN - United Nations

UNEP – United Nations Environment Programme

UNICEF - United Nations International Children’s Emergency Fund

UNSD - United Nations Statistical Division

USGS – United Stated Geological Survey

VLIZ - Flanders Marine Institute

WCMC - World Conservation Monitoring Centre's

WDPA - World Database on Protected Areas

WHO - World Health Organization

WIOD - World Input-Output Database

WTO - World Trade Organization

YCELP - Yale Center for Environmental Law & Policy

1. INTRODUCTION

1.1. MOTIVATION

Our Common Future (also called the Brundtland report) published by the World Commission on Environment and Development) introduced the concept of sustainable development in 1987. It is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development (WCED) 1987). Since the publication of the Brundtland report, there have been several global efforts to promote a sustainable future such as international agreements like the Kyoto Protocol, the Rio + 20 Summit, and most recently the Paris Agreement of December 2015. In 2000, the United Nations launched eight Millennium Development Goals (MDGs) adopted by the United Nations General Assembly (UN 2000). One of the goals was to "*Ensure Environmental Sustainability*", and like the other goals it was envisioned to be based on quantitative metrics. When the MDGs expired in 2015, the international community agreed that the newly developed and improved set of goals, the Sustainable Development Goals (SDGs), would replace them. The new set of goals would serve as an improvement of its predecessor and include time-bound indicators with clear universal targets to be reached by 2030. The 17 SDGs are meant to aspire towards global environmental, economic and social sustainability, and should be universal, easy to communicate and quantifiable in line with the United Nations Commission on Sustainable Development Framework (CSD) (Labuschagne et al. 2005).

The SDGs encompass the three dimensions of sustainability: Economic, environmental and social conditions (Böhringer & Jochem 2007) by including goals concerning biodiversity, land and water in addition to goals to promote equity and human development through poverty abolishment, education, housing, health, security and economic growth (Labuschagne et al. 2005). All three dimensions must be fulfilled for sustainability to be achieved and the link between environmental impacts and human development is crucial for a sustainable future. Human development is dependent on natural resources, and with rising populations and developing countries transitioning to industrialization, exceeding pressure is put on the Earth's ecosystems through increased consumption. Maintaining a sustainable level of resource use and keeping environmental impacts within acceptable limits is one of the greatest challenges of today (von Weizsäcker, E.U. et al. 2014).

Studies have shown that high levels of human development is achievable at moderate levels of energy and GHG emission consumption, and if equally distributed, high levels of human development could be achieved well within current levels of energy and carbon use (Steinberger & Roberts 2010). This is an important finding, because it means that the global population is not dependent on increased levels of consumption to meet their needs, and that the resources available to us are sufficient to sustain us without increasing impacts on the environment. So why is consumption still increasing when our needs seem to be met? Economic growth requires increasing consumption which usually leads to increasing resource depletion and environmental impacts. Achieving sustainability thus depends an absolute decoupling of the economic activity from the ecological limits (Jackson 2009). This calls for more efficient resource use in addition to international policy response (Schandl et al. 2016).

The Earth has a limited amount of resources that should be shared equally along with the environmental burdens caused by consuming them. However, this is an ideal that is not reflected in the huge variations in global consumption patterns, which are ultimately governed by the consumption patterns of individual's and communities' consumption. These consumption patterns can be translated into an environmental footprint to assess impacts along the supply chain of goods and services consumed to determine who and how much is consumed (Hoekstra & Wiedmann 2014).

Contrary to traditional production-based (territorial) accounting, footprinting, or consumption-based accounting (CBA), is a way of measuring sustainability by taking into account both the direct and indirect impacts of consumption. This means that the entire lifecycle of a product or good is assessed (Davis & Caldeira 2010). The PBA approach on the other hand allocates the impacts to the producer and was the method used in the Kyoto Protocol to account for GHG emissions. However, the carbon leakage occurring from relocation of production from developed to developing countries was not detectible using this approach. The result was the apparent reduction in carbon emissions form developed countries, but in reality the emissions had simply shifted to countries not bound be the agreement and the total global emissions increased (Hoekstra & Wiedmann 2014; Davis & Caldeira 2010). This demonstrates the need to account for the emissions and impacts embodied in trade in order to reach a sustainable global consumption level and holding the consumer responsible for the impacts they are causing.

The Kyoto Protocol may have been in-effective in its purpose (Hoekstra & Wiedmann 2014), but its good intensions of quantifying and reducing environmental impact through the use of targets remain important and relevant. This is especially important with respect to policy response. The United States Environmental Protection Agency (EPA) climate change indicators and the United Nations' Human Development Index (HDI) are examples of indicators used to quantify environmental impacts and human development. Quantification and communication of environmental impacts is also a key part of the rationale for both the MDGs and SDGs. Targets are at the heart of sustainable policy making, as well as one of the main drivers of the (MDGs). The MDGs contributed to spark the development of the first Environmental Performance Index (EPI) in response to providing scientific data to support sustainable policy making.

The EPI quantifies 19 different indicators linked to both environmental health (impacts on humans) and ecosystem vitality (environmental impacts) and includes 178 countries. Its proximity-to-target methodology connects sustainability to clearly defined targets by converting countries' environmental performance into scores that can then be used to rank them and allow for comparison between the countries. This feature has led to the EPI being frequently used as a reference for policymaker, the press and the research community (Hsu et al. 2013). The EPI uses a production-based approach, which is sensible for many of the indictors that measure purely territorial impacts (e.g. wastewater treatment). However, this leaves the index prone to the same issues related to PBA as previously described. Several of the EPI indicators are measuring impacts that would benefit from applying a consumption-based approach (e.g. carbon intensity) instead. This way the impacts embodied in trade would be included and result in an improved measurement of sustainability. The development of an alternative consumption-based index is exactly the purpose of this thesis and what is proposed in the following. By exchanging the relevant production-based indicators with equivalent indicators calculated using CBA, this could provide policy makers with a more comprehensive tool for sustainable decision making.

CBA is calculated using a MRIO which is particularly appropriate for footprint calculation as it tracks their origin via multi-national trade flows. MRIO's have been widely used for footprint analysis, and although it has its limitations related to data and aggregation, it is recognized as the best tool for CBA calculation (Wiedmann et al. 2007). There have been several attempts to develop global MRIO databases, for instance the World Input-Output Database (WIOD) (Dietzenbacher et al. 2013), EORA (Lenzen, Moran, et al. 2012; Lenzen, Kanemoto, et al. 2012) and EXIOBASE (Tukker et al. 2009; Tukker et al. 2013) (Tukker & Dietzenbacher 2013). The latter has been developed in three editions, and the most recent version, the EXIOBASE v3 currently under review at *Journal of Industrial Ecology* will be applied here (EXIOBASE Consortium 2015). The EXIOBASE v3 has a high level of sectorial and product detail compared to other available MRIO databases and is well suited for performing environmental impact analysis due to the enhanced disaggregation (Giljum et al. 2016a). These qualities make it a good choice of MRIO database when quantifying impacts using a consumption based approach. A drawback is the limited number of countries (44 countries, mostly European) compared to the EPI's 178.

This study aims to combine the EPI framework and the EXIOBASE v3 account data to create an alternative index which incorporates CBA. The main goal of this thesis is accomplishing a robust ground of results for a detailed investigation into the alternative index. The results of this study will give insight into the benefits and drawbacks of using an existing index and whether the results prove useful in the context of measuring sustainability. The main focus is thus not on the EXIOBASE v3 approach, but rather on the effect of combining it with a policy tool like the EPI. In this context, it serves as a backdrop and only the general development steps and MRIO calculation are rendered.

There is wider recognition for using CBA, commonly calculated with environmentally extended input–output analysis, as a policymaking tool and as a supplement to territorial inventories, particularly when accounting for CO2 emissions (Usubiaga & Acosta-Fernández 2015). However, as far as the author is aware there are no finalized or comprehensive indices combining different consumption-based indicators with production-based indicators into one index as is done in this study. There seems to have been an attempt by the GTAP to create "*A Consumption Based Human Development Index and The Global Environmental Kuznets Curve*" but it does not appear to have been finalized (https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1416). By integrating footprinting into an already existing and widely recognized production based index, the hope is to provide a more comprehensive index to further promote sustainable decision-making by policy makers.

1.2. OBJECTIVE AND GENERAL APPROACH

The objective of this thesis is to develop a consumption-based index by incorporating the EXIOBASE v3 account data into the 2014 EPI. A project thesis was conducted as a preparation for this work with the EPI as its main focus. Thus the EPI focus is continued here, and EXIOBASE serves as a source for consumption based account data. Furthermore, this thesis focuses on the comparison of the original and alternative index. Based on the resulting the effect of incorporating consumption based indicators can be assessed.

This study will apply a consumption based allocation approach redistribute the impacts to the consumer for the purpose of investigating the effect it has on sustainability assessment. The Environmental Performance Index 2014 is a production based index assessing covering both environmental health and ecosystem vitality. A selection of the 19 indicators previously evaluated in the project work of 2015 (Telnes 2015) will be converted into a partially consumption-based index as an alternative to the pure production-based index currently available.

First, the EPI is investigated with respect to its reproducibility, and the alternative index is proposed using EXIOBASE stressors in accordance with the initial tasks of the thesis. The proposed indicators and calculation methods are explained in the Methods and Data chapter. The scores for the year 2011 are calculated to uncover differences and communalities between the original EPI and the alternative index. Then the alternative index is calculated over time between 2002 and 2011 with both production- and consumption-based account data from the EXIOBASE for further investigation. The results of the timeline calculation are then evaluated using three example countries of different economic structure (China, Norway and the US) to determine whether the alternative index is yielding reasonable results in line with other research. Finally, the timeline trends for the same three countries is compared to their respective GDP PPPs to investigate signs of decoupling. All the results are considered in drawing the conclusion of whether the alternative index can be applied in further sustainability assessment.

This thesis addresses the following research questions:

- Is the 2014 EPI methodology reproducible?
- Can the 2014 EPI index and the EXIOBASE v3 database be combined into an alternative index?
- Does the alternative index produce reasonable results in terms of timeline evaluation, and are there signs of decoupling from economic development?
- Based on the findings, is the alternative index recommended for sustainability assessment?

1.3. STRUCTURE

The thesis starts by introducing the 2014 EPI framework and the indicators eligible for CBA conversion before the Theory (2) is presented which includes an introduction to the relevant topics of the thesis and the results of a literature review previously conducted in the project thesis (Telnes 2015). The Methodology and Data (3) describes the statistical methodologies and indicator development of the EPI before presenting the EXIOBASE v3 methodology and data sources. The EPI methodology is then applied as a basis for the general methodology used for creating the alternative indicators. This adapted methodology is then applied to the eligible EPI indicators, and the alternative indicators are proposed and their calculation methods are described in detail. Additional methodology on influence scores and the approach of the timeline analysis is explained. The Results (4) present the findings of the reproducibility analysis of the EPI, followed by an overview of the total adjusted weightings and average influence scores. The alternative index scores are then compared to the EPI scores for 2011 by looking at both the total index and the individual indicators. The timeline results are evaluated and compared to the economic development using three example countries (China, Norway and the US). The findings from the Results are then analysed in the Discussion (5) with emphasis on the 2011 and timeline results before a Conclusion (6) is drawn. Finally, suggestions for future work are presented.

The 2014 EPI colour coding is applied to the relevant figures and tables of this thesis to provide the reader with a clear overview of the study.

Throughout the thesis, EXIOBASE refers to the EXIOBASE v3 and EPI refers to the 2014 edition unless otherwise stated. All mention of *Metadata* is referring to the "*2014 EPI - indicator metadata"* (A Hsu et al. 2014a). All 2014 EPI raw data is downloaded at http://epi.yale.edu/downloads.

1.4. BACKGROUND AND PREVIOUS WORK

A project thesis was completed in the fall of 2015 which will serve as a source of background information for this master thesis. The main goal of the project was to provide a comprehensive literature review covering the 2014 EPI methodology, and the concept of consumption based accounting and input-output analysis. This study based on the results of the project thesis, and thus some of the findings will be recited here. Whenever the project thesis is used, the reader will be informed of this in the relevant sections are referenced as Telnes 2015. Additional background data from the project relevant for this thesis is provided in the appendix.

The following sections give an introduction to the 2014 EPI framework and the history behind it.

1.5. 2014 EPI

This section introduces the background and framework of the EPI.

1.5.1. HISTORY AND DEVELOPMENT OF THE EPI

When the eight United Nations Millennium Development Goals (MDGs) were adopted by the United Nations General Assembly in 2000 (UN 2000), they were envisioned to be long-term goals achieved by 2015, and based on quantitative metrics. For most of the goals there were relevant metrics available. However, the seventh goal (MDG 7) "Ensure Environmental Sustainability" lacked such underlying metrics necessary to reach it, as well as establishment of relevant policies. A collaboration between Yale Center for Environmental Law & Policy (YCELP), the Center for International Earth Science Information Network (CIESIN) at Columbia University and the World Economic Forum resulted in the development of the EPI's predecessor, the Environmental Sustainability Index (ESI). The same year as the MDG's were launched, the ESI was published, partly as a response to the data gap of MDG 7. This joint project of providing scientific data to support sustainable policy making has been ongoing for more than a decade, its latest feature being the 2014 EPI which includes 178 countries representing "*99 percent of global population, 98 percent of land, and 97 percent of global gross domestic product (GDP)*" (A Hsu et al. 2014d; United Nations n.d.; Hsu et al. 2013). Both the ESI and the EPI were created with the aim of shaping data-driven environmental policy making. The EPI is published biannually (A Hsu et al. 2014c; Telnes 2015).

1.5.2. EPI FRAMEWORK

The EPI ranks the performance of 178 countries on high-priority environmental issues in two broad policy areas. The two main policy objectives are: Environmental Health measuring the protection of human health from environmental harm, and Ecosystem Vitality measuring ecosystem protection and resource management. These are further divided into nine issue categories and 20 indicates (Environmental Performance Indicator 2014; A Hsu et al. 2014c). The framework is illustrated in Figure 1 where the issue categories are shown by objective to the left. The selection of the two main objectives followed the EPI developers' intention of providing policy makers with a useful decision-making tool, as a consequence of the fact that measures taken to improve environmental issues often are prioritized in line with the needs of people and ecosystems (Hsu et al. 2013; Telnes 2015). More information on data sources, indicators and rationale for inclusion can be found in Appendix F and H.

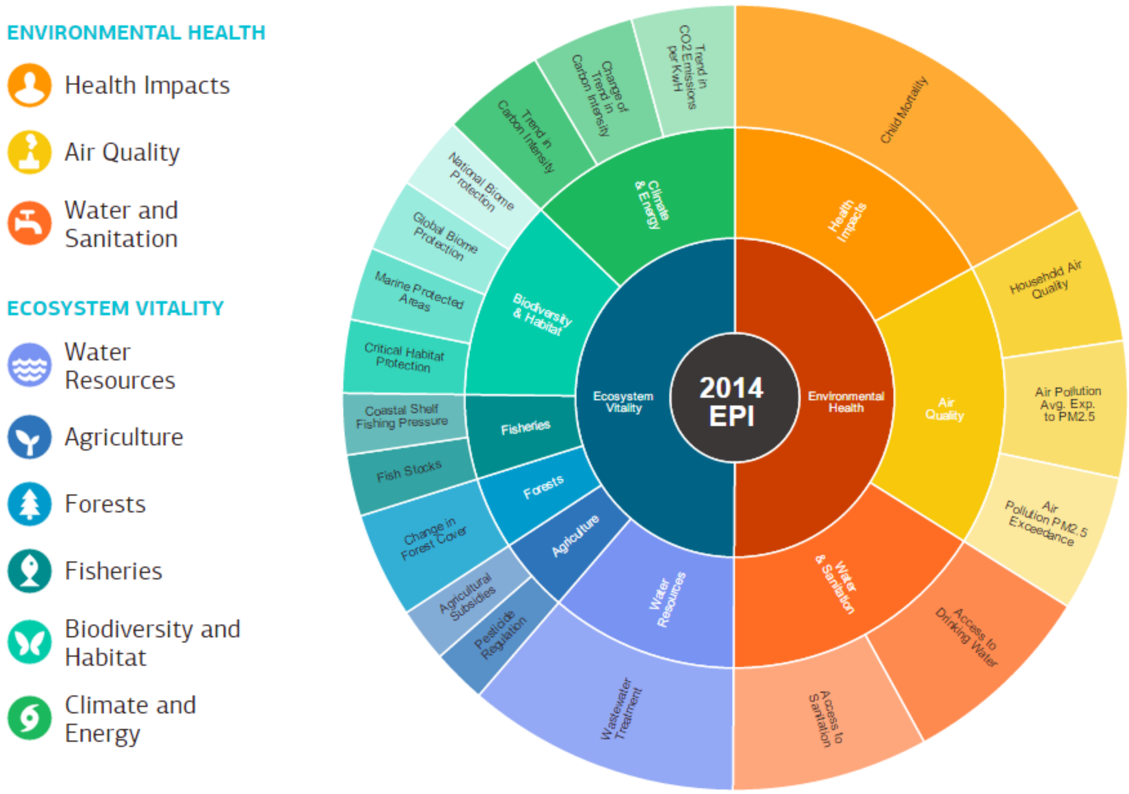


Figure 1: 2014 EPI framework. Access to electricity is not included as it was not used for the index calculations (A. Hsu et al. 2014).

The EPI uses indicators to measure environmental aspects at a national level (A Hsu et al. 2014c). An aggregate of environmental indicators make up an environmental index (de Sherbinin et al. 2013).

1.5.3. ENVIRONMENTAL ACCOUNTS INCORPORATED

The two policy objectives for environmental protection were chosen after reviewing existing policy goals and literature to reflect the policymakers' priorities with regards to environmental and natural resource protection. These priorities were especially linked to the section of the United Nations Millennium Development Goals (MDGs) concerning the environment. The scope of the underlying issue categories are designed to be relevant, cover existing data and be in line with established policy goals in a measurable way (Hsu et al. 2013) (Telnes 2015). A summary of the EPI's qualitative framework listing each environmental account is found in Appendix F.

1.5.4. EPI ACCOUNTING SCHEME

The EPI is calculated based on territorial data for each country, thus it uses a territorial (or production-based) accounting approach. Although this approach is sensible for some indicators of national concern like *Child Mortality* and *Access to Sanitation*, it is not necessarily the best way to portray indicators affected by non-territorial activities. Examples are the *Air Pollution* indicators where the pollution level depends on consumption pressures from foreign countries in addition to the domestic consumption. Other environmental fields are also affected by non-domestic consumption. According to an article by Lenzen et al. (2012) on biodiversity in connection with trade and consumption, much of the habitat loss in many countries is due to production aimed for consumption elsewhere (Lenzen, Moran, et al. 2012). The use of PBA only considers impacts from domestic production and consumption, which may hide contributions from other countries' activities. Thus potential continental or global interconnections may be lost from consideration. As de Sherbinin et al. (2013) stated, the EPI "*inadequately captures the environmental impacts of trade flows.*" (de Sherbinin et al. 2013). This indicates that incorporation of a different accounting scheme (like CBA) could be an appropriate compensation for this inadequacy (Telnes 2015).

In light of the argumentation above, an eligibility evaluation was conducted to reveal which 2014 EPI indicators could be adapted into CBA indicators.

1.5.5. 2014 EPI INDICATOR ELIGIBILITY FOR CBA APPLICATION

This thesis uses the EPI 2014 framework as a guide to construct a consumption-based index. Although the EPI 2014 is a production-based index, some of its indicators have the potential of being adaptation to a consumptions-based approach. An evaluation of all the indicators was conducted by Telnes (2015) and the results are presented in Table 1-Table 4. The table lists each indicator and a justification of its deemed relevance for a consumption-based index. The justification is based on the argumentation that follows on accounting schemes. The conclusions drawn from the project thesis will be used as a basis for the indicator development of this master thesis.

Table 1: Evaluation of the 2014 EPI indicator's eligibility for conversion to a consumption-based accounting scheme extracted from the project thesis (Telnes 2015). This table shows indicators evaluated to be ineligible for application in a consumption-based index.

EPI indicator	Eligibility	Justification
Child Mortality	Not relevant	Depends on the economic and social support system of public authorities as well as other factors not directly linked to international consumption (Rosling 2015).
Household Air Quality	Not relevant	Assuming this depends on the type of cooking utensils available it is a local issue not created by international trade flows.
Access To Sanitation	Not relevant	Amount of available sanitation sources. Not related to international trade or consumption of goods. Human health measure.
Access To Drinking Water	Not relevant	Quantification and classification of sources and access to drinking water.
Wastewater Treatment	Not relevant	Wastewater content varies according to the source of origin (i.e. household or industry). One could argue that the expected impacts from industrial wastewater would be larger in industrialized areas. However, this would depend on the ratio of wastewater treatment and treatment methods, and not directly on the industry causing the wastewater. For this reason, it is considered irrelevant here.
Pesticide Regulation	Not relevant	Law and policy related, not dependent on specific production or consumption pattern. Alternatively, instead of the Regulation policies, a new index could directly incorporate pesticide use. In that case, this category could be assess using CBA.
Terrestrial Protected Areas (National Biome Weight**)**	Not relevant	This is a direct measure of protected land area which makes it not directly applicable for CBA. However, the land area under protection is in competition with land are used for economic activities like agriculture and forest use. It could be measured with a bio diversity footprint, or with the land/ forest footprint suggested for Change in Forest Cover.
Terrestrial Protected Areas (Global Biome Weight**)**	Not relevant	Following the argumentation for National Biome Weight above, it could also be necessary to conduct future research on how to measure the exact location of the land use change, and identify whether it occurs in a protected area or not.

Table 2: Evaluation of the 2014 EPI indicator's eligibility for conversion to a consumption-based accounting scheme extracted from the project thesis (Telnes 2015). This table shows indicators evaluated to be ineligible for application in a consumption-based index.

EPI indicator	Eligibility	Justification
Marine Protected Areas	Not relevant	This is a direct measure of the portion of the exclusive economic zones (EEZ) that is protected. The amount of area set aside for protection may depend on many factors including the possible gain from economic exploitation instead. However, these concerns would be covered in the Fisheries issue category.
Critical Habitat Protection	Not relevant	A measure of protected area. As for the marine protected areas, it is in conflict with land areas usable for economic exploitation. However, this could be included in the change in forest cover indicator, of with terrestrial protected areas. Alternatively, a combination of agriculture, change in forest cover and terrestrial protected areas to create a single indicator for land use change due to consumption.
Access To Electricity	Not relevant	Quantification of amount of population with electricity access. Not related to trade flows.

Table 3: Evaluation of the EPI 2014 indicator's eligibility for conversion to a consumption-based accounting scheme extracted from the project thesis (Telnes 2015). This table shows indicators evaluated to be eligible for application in a consumption-based index.

EPI indicator	Eligibility	Justification
Air Pollution Avg. Exp. To PM2.5	Relevant	Pollution from producing goods and services for export. Air pollution can originate from many different sources (e.g. road traffic), but in this context the air pollution associated with production of exported goods (factories, agriculture) are the main interest. The impacts from emission of polluting agents like PM2.5 should be attributed to the consuming country.
Air Pollution PM2.5 Exceedance	Relevant	Pollution from producing goods and services for export. Same argumentation as for the average exposure.
Agricultural Subsidies	Relevant	While the subsidies indicator itself may not be the optimal way to determine impacts from agriculture, an alternative is proposed: An indicator considering the consumption and export of agricultural products is suggested or a combination/aggregation (see *Critical Habitat Protection*). Alternatively, a measure of productivity could be applied. Weight by bio-productivity (Tukker et al. 2014).

Table 4: Evaluation of the 2014 EPI indicator's eligibility for conversion to a consumption-based accounting scheme extracted from the project thesis (Telnes 2015). This table shows indicators evaluated to be eligible for application in a consumption-based index.

EPI indicator	Eligibility	Justification
Fish Stocks	Relevant	Global demand for food products of marine origin. Associated impacts resulting from export, like overexploitation of ecosystems and fish stocks are attributed to the consumer.
Costal Shelf Fishing Pressure	Relevant	Global demand and export of food products of marine origin. Associated impacts resulting from fishing methods, like damaging of ecosystems (e.g. sea floor) are attributed to the consumer.
Change In Forest Cover	Relevant	Direct measure of land use change caused by consumption. This could be measured using the land footprint, as available through the EXIOBASE database. Could also be measured with regards to type of agriculture or land use that replaces the forest (e.g. forest use footprint). This way one can have proxy measure of whether it is for export or not (e.g. palm oil, rape seed). An indicator depicting the trend in consumption based land use change could also be applicable (like the already existing indicators in the Climate and Energy issue category). Requires detailed knowledge of supply chains and locations of resource extraction. Some resources may also be residues from other production chains, which may complicate the accounting (LCA boundaries, attribution method). Distinction between forest and arable land.
Trend In CO_2 Emissions Per kWh	Relevant	This is linked to the promotion of sustainable energy use and production. It is relevant due to indirect impacts from energy use in different sectors. Determining which sectors are using the energy to produce exportable goods and services should be distinguished and included in the total impact account.
Change Of Trend In Carbon Intensity	Relevant	Follows the same argumentation as the Trend in Carbon intensity below.
Trend In Carbon Intensity	Relevant	Carbon intensity is an important issue, and as mentioned in the chapter on CBA the incentives for exporters to lower carbon intensity is reduced when the emission is allocated to the importer. This indicator is important for determining type of product and energy type used to produce it.

2. THEORY

This chapter presents the theoretical background for the methods applied in this study. First, the concept of environmental indicators are defined and related issues presented. The PBA and CBA accounting schemes are then presented in relation to measuring environmental impacts related to trade flows, and further how these can be calculated using MRIO. The environmentally extended MRIO database EXIOBASE v3 applied in this thesis is then presented with regards to its suitability for environmental impact assessment. Finally, the principles of impact decoupling are presented.

2.1. ENVIRONMENTAL INDICATORS

An indicator is defined as a metric that that represents a state (J. P. G. Jones et al. 2011). Environmental indicators are described by (OECD 1991) as "*metrics derived from observation (i.e. data) that are used to identify indirect drivers of environmental problems (e.g. population or consumption growth), direct pressures on the environment (e.g. overfishing), environmental conditions (e.g. air pollution concentrations), broader impacts of environmental conditions (e.g., health outcomes), or effectiveness of policy responses*" as cited by (de Sherbinin et al. 2013). Indicators are useful tools for policy making as well as providing information on the environmental, economical, societal and technological development performance of countries (Singh et al. 2012). They are also helpful for efficiently allocating scarce resources and act as a driver towards policy goals.

As of 2003, there had been more than 500 efforts to quantify sustainable development through indicators. They are an important tool for decision-making, consensus building, and research and analysis. However, because of the ambiguous nature of sustainable development and its varying characterization and measuring purpose, there is no universally accepted set of indicators. Confusion surrounding terminology, data and measurement methods complicates the creation of an indicator set that is universally agreed on, supported by rigorous data, theory and methodology, and has influence on policies (Parris & Kates 2003). Following this, it is evident that the creation of environmental and socioeconomic indicators is not a simple and straightforward procedure. This leads to a variance in the choice of indicators depending on the desired purpose.

The EPI includes 20 different environmental indicators distributed between nine issue categories. They are selected from extensive scientific literature reviews with the goal of measuring countries' progress towards long-term sustainability targets of the two main EPI objectives (A. Hsu et al. 2014) (Telnes 2015).

2.2. ENVIRONMENTAL ACCOUNTING SCHEMES

2.2.1. PRODUCTION- AND CONSUMPTION-BASED ACCOUNTING

Indicators can be applied to measure environmental impacts using two main approaches; a production-based approach or a consumption-based approach. In short, the first accounts for the impacts of production, while the latter accounts for the impacts of final demand. The PBA approach was used in the Kyoto protocol and measured pressures and impacts originating from economic activities (e.g. production and emissions) within a nations' territory (Lenzen, Moran, et al. 2012). In contrast, the CBA framework (also called footprinting) accounts for all impacts connected to the production of goods and services and allocates the related impacts to the county of final consumption using life cycle principles (Davis & Caldeira 2010). This includes the emissions embodied in imports and the emissions due to domestic production for domestic consumers, but excludes emissions due to the production of exported commodities. If applied to a certain emission type or environmental impact, this framework is used to calculate footprints of various kinds (carbon footprint, land footprint or water footprint). Footprinting allows for a quantifications of the total human pressure on the environment or "(…) *how much of the available capacity within the planetary boundaries is already consumed*" (Hoekstra, A.Y., Wiedmann 2014; Tukker et al. 2014; Davis & Caldeira 2010).

There are two kinds of environmental impacts related to consumption: direct and indirect. As the name suggests, the direct impacts are the ones related to impacts stemming from direct use of for instance fossil fuels in the form of petrol used in cars. They are typically within the boundary of the use phase of a good or service. The indirect impacts are related to the embedded impacts (e.g. emissions) of the other phases in the lifecycle of a good or product, such as manufacturing, raw material extraction and waste management. These phases are necessary for the end consumption in the use phase, and should thus be considered when looking at the entire impact of a good or service. This is the objective of a Life Cycle Assessment (LCA) (Hertwich & Peters 2010; Huijbregts et al. 2007). Determination of indirect environmental impacts is made more difficult by increased international trade due to the spread of impacts (like emissions) over several geographical regions (Peters & Hertwich 2006).

2.2.2. ADVANTAGES OF CBA

CBA makes a good alternative approach to the PBA's traditional focus on territorially generated environmental pressures and impacts. Switching to a consumption-based approach enables the evaluation of the extent to which environmental problems are being relocated between regions due to increased imports of resource-intensive products.

The global market of today contains major trade flows that mainly run from developing countries to the developed ones. Especially China, which constitutes a considerable origin point for embodied emission flows, not only through export, but also through energy production in other regions of Asian and Oceania. The economic growth in these regions will continue to contribute to this energy trade flow (Kanemoto et al. 2013). Figure 2 shows that the major global trade flows of embodied CO_2 emissions are going from net exporting countries in blue to net importing countries in red (Davis & Caldeira 2010). Similar trends of carbon footprints (GHG-emissions measured in CO_2-equivalents embodied in trade) are depicted in the CREEA booklet calculated using EXIOBASE 2.1 (page 15) which states that Europe and the United States (US) are the two largest net importers of natural resources in the world (Tukker et al. 2014). In both figures, China stands out as a major net exporter.

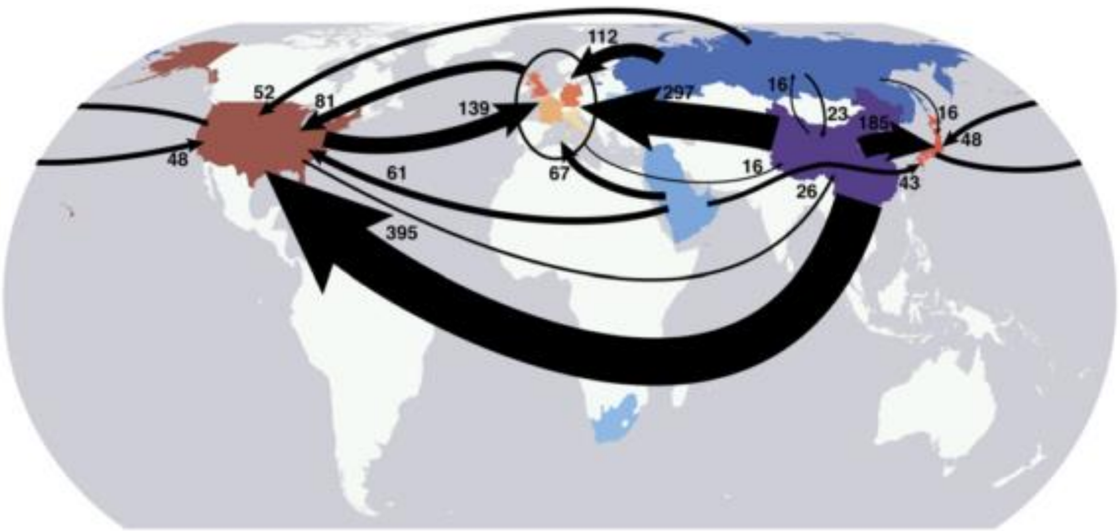


Figure 2: Main fluxes of emissions embodied in trade (Mt CO_2 y^{-1}) between regions (Davis and Caldeira 2010).

The major exporter of GHG-emissions in 2007 was Asia. These exports were destined for either Europe or North America. This shows how foreign emissions from consumption comes in addition to the already large carbon footprint of these latter regions (Tukker et al. 2014). This trend is illustrated by Kanemoto et al. (2013) in Figure 3 where the dotted line represents consumption and the black line represents territorial emissions. The blue field shows the net exported CO_2 emissions from developing to developed countries, while the red field shows the net import of developed countries. The graph shows that although the territorial emissions in the developed countries have stabilized and slightly decreased, the consumption-based emissions have increased. This is due to the net import of emissions from developing countries, where the territorial emissions have gone up, but the consumptions has stayed below the production level (i.e. net export of emissions).

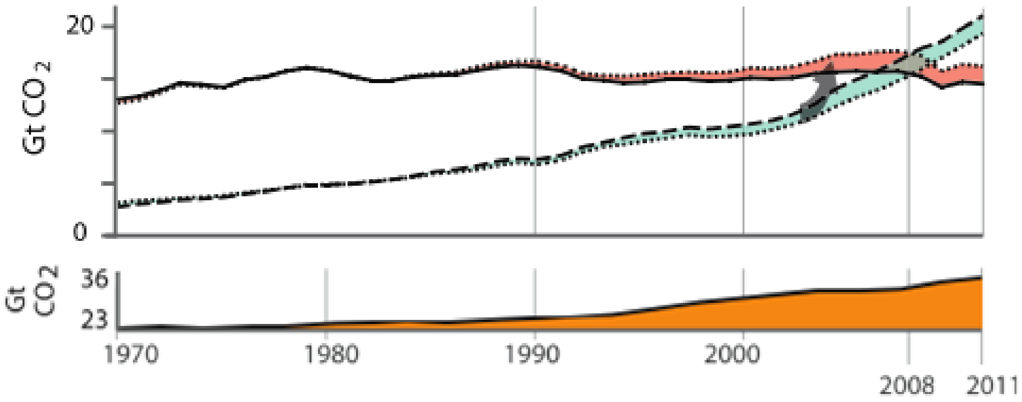


Figure 3: Net export and import of CO_2 emissions, and cumulative CO_2 emissions (Gt CO_2). Adapted from (Kanemoto et al. 2013)

At the same time the orange field in the lower graph shows that total global emissions have increased since the 1990's. The study also suggests that CO_2-intensive production may relocate to avoid regulation (Kanemoto et al. 2013).

A central point of CBA is that it looks at the exports and imports which are the origin of the flows of embodied emissions. This is closely linked to carbon leakage. There are two types of carbon leakage: strong leakage as a direct response to climate policy, and weak leakage due to industrial expansions. The latter type is thought to undermine efforts to regulate carbon emissions (Davis & Caldeira 2010). This is a trend that shows the limitation of PBA compared to CBA. An example is the Kyoto protocol targets, where many industrialized countries seem to have reached their emission reduction targets. However, as explained above, the total global emissions have increased, and only the locations of the emissions have shifted. The emissions from consumption are still there, but they are being produced in developing countries (Kanemoto et al. 2013).

Production is allocated to emerging economies where the remaining resources are found, and where there are cheap and skilled labour forces (Hertwich 2011). Apart from leaving them with the environmental impacts resulting from the economic activity pressures, it also provides economic growth for the producing countries. A substantial fraction of the growth in these countries stems from covering the consumer demand of developed countries. That being said, it does not change the fact that environmental impacts are unfairly distributed across the globe. "*The geographical separation of production and consumption complicates the fundamental questions of who is responsible for emissions and how the burden of mitigation ought to be shared*." (Davis & Caldeira 2010).

The question of who should bear the burden, consumer or producer, is one of the reasons why a new international climate agreement (e.g. Paris Conference of Parties (COP21) http://www.cop21paris.org/) has been so difficult to achieve. Many developing countries argue that the industrialized countries were able to reach the level of development they have today without any restrictions on emissions. Thus, the developing countries of today should be allowed to do the same, and emit more, as stated by the Indian prime minister (Lote 2015). These concerns of historical and regional emission inequities could be resolved by sharing the responsibility for emissions among producers and consumers. This could also help facilitate international agreement on global climate policy (Davis & Caldeira 2010).

2.2.3. LIMITATIONS OF CBA

CBA could solve some of the problems connected to just allocation of emission responsibility. When the consuming countries are accounted for the emissions of their imports, they will have an incentive to either reduce their consumption of imported goods, or change their consumption pattern to less emission intense products. This would give the producers an incentive to reduce the emission intensity of their production in order to become more attractive to the consumer. However, such consumption choices could require knowledge and insight into not only the production of the good but the entire supply chain, which may not be available to the consumer (Hoekstra & Wiedmann 2014).

Although CBA has many appealing qualities related to environmental impact accounting, the paradoxical problem is that by shifting the impacts to the consumer, the producer is suddenly alleviated of impacts from exports. This reduces their incentives to decrease important impact factors like carbon intensities in their production (Peng & F&ES'17 2015). National studies, showed that pollution intensity is higher for emerging economies, and these are also the centers for global manufacturing (Hertwich 2011).

2.3. PRINCIPLES OF MULTIREGIONAL INPUT-OUTPUT ANALYSIS

The CBA approach calculates impacts using MRIO (Davis & Caldeira 2010). The MRIO approach provides a means of calculating the direct and indirect environmental impacts of human activities (Acquaye et al. 2017). There is raised interest in accurately quantifying the embodied impacts from traded products as globalization of production networks has increased (Hertwich & Peters 2010). The MRIO is an extensions of the standard input-output analysis (IOA) developed by Wassily Leontief in 1941 (Peters et al. 2004). IOA is a method within economic theory describing the structure of an economy. Input-output tables (IOT) consider flows between industrial sectors i.e. amount produced within each sector, and the inputs used. For instance, pollution data from each sector are used to determine environmental impacts related to consumer purchases (embodied pollution) (Huijbregts et al. 2007; Peters & Hertwich 2006). This extends the classic economic MRIO calculations to an EE MRIO analysis. In order to conduct footprint accounting, the underlying environmental accounts that are methodologically sound, and these must comply with both the System of National Accounts (SNA) and the System of Environmental Economic Accounting (SEEA) (Usubiaga & Acosta-Fernández 2015)

MRIO tables have been around since the 1950s and have become a widely used tool for regional policy (Tukker & Dietzenbacher 2013). In addition, they have a high relevance for climate policy issues related to carbon leakage, consumer behavior and account for demand-induced pressures of global production networks (Wood, Stadler, Bulavskaya, Lutter, Giljum, de Koning, Kuenen, Schütz, Acosta-Fernández, Usubiaga, Simas, Ivanova, Weinzettel, J. H. Schmidt, et al. 2015). The concept of consumption-based accounting has been widely used for assessing carbon footprints, however, it has been used for many other environmental pressure categories. Using carbon footprints are increasingly recognized as a complement to traditional territorial emission inventories (Usubiaga & Acosta-Fernández 2015). In addition, using EE MRIOs tables to describe environmental impacts caused by the complex global economic relationships is emerging as the main tool for this purpose. The format of EE MRIOs is also in compliance with the aforementioned SEEA (Stadler et al. 2017). That being said, despite the increased use of environmental extension over the last years, their methodological soundness has not been paid sufficient attention (Usubiaga & Acosta-Fernández 2015). The EE MRIOs have low product resolution, and its sector and product aggregation is its main disadvantage. The aggregation means that all products and economic sectors are assumed to be homogenous, and hundreds of different products are aggregated into a few product groups. Doing this benefits from including all internationally traded products, but it does so by sacrificing a higher level of detail (Weinzettel et al. 2014).

The aggregation is also a consequence of the problems related to data availability and the amount of data required to conduct an MRIO analysis. To overcome these issues of data requirement, some common assumptions are made; *Uni-directional trade* assuming the domestic region trade with all other regions, but no trade is taking place among the other regions, and the *Import assumption* (i.e. domestic technology assumption) assuming the regions trading with the domestic region are all using the same technology (e.g. Norway trading with China would assume that goods are produced using hydro power). This lowers data requirements but enhances errors. In addition, data availability varies across countries, where the OECD provides a good set of data for an MRIO, while non-OECD countries have less data availability and often is only available for the major countries in this group (Peters & Hertwich 2009).

IO-tables are compiled from Supply and Use tables (SUTs), however since these are often non-symmetrical an assumption must be made to create a symmetrical IO-table. The symmetry can eiter be based on product-by-product of industry-by industry. There are two main assumotions: industry technology assumption of product technology assumption. The first assumes that each industry is producing all its priducts using the same technology, while the latter assumes that each produc has itsown technology for prooduction irrespedtive of th indusrtry that produces it (Eurostat - European comission 2008). The industry techonolgy assumption is suggested applied by Peters & Hertwich (2009) since emissions data are always given in accordign to the industry classification and thus requires less data manipulation, although modificaions may be necessary for cases of final demand using the product technology assumption (Peters & Hertwich 2009).

Despite the data limitations, it has been concluded that a global MRIO is the most appropriate and accurate analytical method to estimate ecological footprints, and to allocate pollution and resource use embodied in trade (Wiedmann et al. 2007). There are several MRIO databases available, and examples of the most ambitious projects are World Input-Output Database (WIOD) (Dietzenbacher et al. 2013), *EORA* (Lenzen, Moran, et al. 2012; Lenzen, Kanemoto, et al. 2012) and EXIOBASE (Tukker et al. 2009; Tukker et al. 2013) (Tukker & Dietzenbacher 2013)

2.4. EXIOBASE v3

The EXIOBASE v3 is the third and most recent edition of the EXIOPOL project funded by the European Union (EU) to sought to improve insight in the external costs caused by environmental pressures, as well as the data limitations IO tables and multiregional environmentally extended SUTs (MR EE SUTs) (Tukker et al. 2013; Wood, Stadler, Bulavskaya, Lutter, Giljum, de Koning, Kuenen, Schütz, Acosta-Fernández, Usubiaga, Simas, Ivanova, Weinzettel, J. H. Schmidt, et al. 2015). This project has evolved into the current EXIOBASE version, which is a global Multi-regional Environmentally Extended Supply and Use / Input Output (MR EE SUT/IOT) database (EXIOBASE Consortium 2015). In contrast to the previous versions, this edition provides a timeline perspective covering the years 1995-2011. It assesse 44 countries in detail, out of which 28 are European and the remaining represent the EUs majors trading partners, which reflects the databases purpose of environmental assessment of the EU. Furthermore, five Rest of World (RoW) regions are includes, and together with the 44 countries it covers up to 95% of the global GDP. However, compared to other MRIO databases (EORA has 187 countries/regions), this is a relative low country coverage which is a drawback of the EXIOBASE, but for assessing EU's global environmental impacts it is a very suitable database. Moreover, the database covers 200 commodities as well as 163 industries. This level of detail by country is the highest across all currently available MRIO databases. In particular, its detail level with respect to material flow represent a major advantage (Giljum et al. 2016b; Wood, Stadler, Bulavskaya, Lutter, Giljum, de Koning, Kuenen, Schütz, Acosta-Fernández, Usubiaga, Simas, Ivanova, Weinzettel, J. H. Schmidt, et al. 2015).

The EXIOBASE v3 is developed using the same main steps as the EXIOBASE 2.1. There are four main steps; Creating harmonized SUTs, adding extensions, linking environmentally extended SUTs via trade, and creating a global EE MRIO (Tukker et al. 2016). For further details on the EXIOBASE development the reader is referred to (Tukker et al. 2009; Tukker et al. 2013; Wood et al. 2014; Wood, Stadler, Bulavskaya, Lutter, Giljum, de Koning, Kuenen, Schütz, Acosta-Fernández, Usubiaga, Simas, Ivanova, Weinzettel, J. Schmidt, et al. 2015). The environmental extensions, or stressors, can be combined to characterize specific environmental impacts, where the only requirement is that the stressors have the same unit so that they may be added together.

The EXIOBASE 2.1 has been applied in the CREEA booklet (Tukker et al. 2014), as well as a recent study by Tukker et al. (2016). The latter considered four important environmental footprints (carbon, land, water and materials) and how they differ from the production based accounts, and it was found that the EU27 have a larger footprint than territorial impacts for all four footprint categories. Rich developed countries have generally higher footprints than the less developed countries like India and Indonesia. There were differences in which footprints are more significant for the different countries, but the trends is clearly that footprints are higher for the developed countries (Tukker et al. 2016).

2.5. DECOUPLING

"According to the OECD, the term decoupling 'has often been used to refer to breaking the link between the growth in environmental pressure associated with creating economic goods and services'."(Desha et al. 2010). There are two types of decoupling; relative and absolute. These are also referred to by Ward et al. (2016) as weak and strong decoupling respectively. Ward et al. (2016) defined relative decoupling as " *(...) higher rates of economic growth than rates of growth in material and energy consumption and environmental impact*" (Ward et al. 2016). According to Professor Tim Jackson *"Relative decoupling refers to a decline in the ecological intensity per unit of economic output."*(Jackson 2009). As the name implies, relative decoupling differs from absolute decoupling in that it is a sign of increased efficiency, rather than a decline in absolute terms which is a sign of the latter. Absolute decoupling is essential for the economic activity to stay within ecological limits (Jackson 2009; Ward et al. 2016).

The current consumption models that the global economy are based on are not sustainable. Natural resources like freshwater, land and soil, and fish are vital for prosperity yet many have increased beyond sustainable levels (von Weizsäcker, E.U. et al. 2014). If equally distributed however, human needs at high levels of human development could be achieved well within current levels of energy and carbon use. High human development is defined by the United Nations' Human Development Index (HDI) and has been found to be achievable at moderate levels of energy and GHG emission consumption (Steinberger & Roberts 2010). The same result can be seen for footprints, where after a certain level of consumption is reached, the human development increase levels off (Tukker et al. 2016).

According to one study by Ward et al (2016), different countries and regions have different trends of decoupling for GDP, material use and energy use between 1990 and 2012. Relative decoupling has been observed in China with GDP rising at a much higher rate (factor of 20), compared to the energy and material use (factor of ca. four and five respectively). The OECD showed slower rise in GDP, and the energy and material consumption was flattening. Globally, only relative decoupling is seen (increasing energy and material use), but the trend for the OECD gives hope of absolute decoupling being achievable (Ward et al. 2016).

A gradual decoupling of energy and carbon from human needs is observed by Steinberger & Roberts (2010) meaning that human well-being is becoming more efficient. However, efficiency comes at a price known as the rebound effect (Jevon's Paradox), where consumption increases because other means are freed to further consume (e.g. cheaper electricity opens up for increased consumption of electricity as well as other goods because of freed capital). Thus, efficiency alone cannot be expected to result in absolute decrease in energy use (Steinberger & Roberts 2010). In addition, one of the main mechanisms that give the appearance of decoupling when there isn't one is the export of environmental impacts between regions (Ward et al. 2016).

In order to achieve decoupling, there is a need of changes in policies, corporate behavior an consumer patterns (Fischer-Kowalski et al. 2011). Highly developed countries could still maintain their level of human development by using a fraction of the energy they are currently using. This give hope for a restructuring towards absolute decoupling, but it is not a process that will happen easily, as it goes against the growth driven economic system where increasing levels of consumption are required to support production and employment (Steinberger & Roberts 2010; Jackson 2009)

3. METHODS AND DATA

The statistical methods applied by the EPI are presented first, followed by the indicator development methodology of the 2014 EPI. The EXIOBASE v3 methodology is then introduced before continuing on to the calculation methods applied to convert the selected EPI indicators into CBA indicators using EXIOBASE data. The individual calculation methodologies of each indicator are then explained in detail followed by a presentation of the influence scores. Finally, a section on the procedures of the timeline investigation and decoupling is presented.

3.1. STATISTICAL METHODS OF THE EPI RAW DATA EVALUATION

3.1.1. DETERMINING RAW DATA DISTRIBUTION

The EPI raw data distribution is evaluated according to the most important probability distributions of statistics, namely the normal distribution. The normal distribution is a continuous probability distribution with a bell-shaped curve whose peak is the mean value. The area under the curve is equal to 1 representing the probability (Walpole et al. 2012). Whenever the EPI raw data distribution is abnormal, a logarithmic transformation is used to correct for this. The EPI methodology does not specify which test for normality is used, so a normal quantile-quantile plot (Q-Q plot) was chosen for this purpose as it provides a good visualization of the data distribution.

The normal Q-Q plots uses what is known about the quantiles (or percentiles) of the normal distribution and plots them against the empirical quantiles of the raw data set. If the raw data is normally distributed there should be a linear relationship between the raw data distribution and the normal distribution. Like the EPI raw data, the raw data of the alternative indicators were checked for normality. This was done by plotting the alternative raw data against the normal probability distribution based on a percentile rank calculated using Equation (**1**) (Walpole et al. 2012).

$$p_i = \frac{i - \frac{3}{8}}{n - \frac{1}{4}} \tag{1}$$

Here, n is the total number of observations (44 countries in this case). The countries raw data calculations are sorted from smallest to largest, and each observation i is assigned a corresponding value from 1 to 44. The distribution of the alternative raw data set can then be compared to the normal distribution quantiles by plotting them against each other. The normal distribution quantiles were calculated by applying the NORM.INV function in Excel to the percentiles p_i.

3.1.2. WINSORIZATION

This statistical concept limits the extreme values of a dataset without eliminating them. Instead, the extreme values are replaced by the value of the chosen percentile seeking to trim the tails of the maximum and minimum values in the dataset (Dixon & Yuen 1974; Hastings et al. 1947). It is briefly introduced here because of its stated application in the EPI methodology guide "*Measuring Progress: A Practical Guide From the Developers of the Environmental Performance Index (EPI)"*(Hsu et al. 2013). However, as we will see, the method described in this section is not followed and its exact mode of application is described in further detail in the indicator development section.

3.2. INDICATOR DEVELOPMENT METHODOLOGY OF THE 2014 EPI

The 2014 EPI developers' justification behind the choice of indicators incorporated in the index were presented in the Introduction chapter. The process of creating the EPI indicators from the chosen data sources is divided into three main parts; determining targets used for score calculation, calculating the indicators, and weighting and aggregating of the indicator scores to produce the final index scores. These main steps are described in the following and draw upon the methodology presented in "*Measuring Progress: A Practical Guide From the Developers of the Environmental Performance Index (EPI)*" (Hsu et al. 2013).

3.2.1. DETERMINING TARGETS

The 2014 EPI ranks countries based on the score they receive for each indicator. The scores range from 0-100 and are set through the use of targets (performance benchmarks). Since the indicators are measured using different types of data, scores are used to make a country's performance relative to a defined policy target comparable across indicators. The high and low performance benchmarks represent the top and bottom performers respectively. They are determined by the EPI research team and set based on biological thresholds, policy goals or on expert judgement in order to arrive at targets that best represent the goal of the index. The low performance benchmark (LPB) is equivalent to the lowest score (zero) on the 0-100 scale, while the high performance benchmark (HPB) represents the top score of 100. Any country achieving or exceeding the HPB receives a score of 100. The LPB is usually established by the worst performing country of a particular indicator. However, the EPI methodology states that a Winsorization at the 95th percentile may also be used for this purpose (Hsu et al. 2013). As mentioned, further investigation reveals that the 2014 EPI has not applied the Winsorization quite according to the statistical theory. This issue is revisited in section 3.1.2.

In most cases, the targets are set using expert opinion, which means that the source or justification for the target is not obtainable, as its origin is not specified by the methodology or metadata. This makes it difficult to translate them into the alternative consumption based index as will be discussed in later sections.

3.2.2. INDICATOR CALCULATION

The 2014 EPI indicators are calculated using three main steps in the following order: first the *Data Preparation*, then the *Data Transformation* and finally the *Data Conversion to Indicators*. When these three steps are finalized, weighting and aggregation is applied to the indicator scores to arrive at the combined 2014 EPI score for each country.

3.2.3. DATA PREPARATION

The first step serves as a preparation for further use of the raw data sets. There may be issues of missing values for certain countries, either due to the country being excluded, not being applicable to the indicator, or simply that its value is missing. The countries that have missing values due to applicability issues are listed in a materiality filter whose implications will be discussed shortly with regard to the indicator calculation. Normalization is also used for some of the indicators to make them comparable across entities. Common denominators include percent change, units per economic output, units per area or units per population.

3.2.4. DATA TRANSFORMATION

In the second step, raw data sets that are heavily skewed to the left or right are corrected for abnormal distributions through logarithmic transformation using the natural logarithm. Sometimes the data does not match the rest of the framework, and an inversion is needed to make it fit. An example of this is when a performance target is at the opposite end of the scale compared to the targets of the other data. A target of 100 percent of *Critical Habitat Protection* implies good environmental performance, however applying this target to *Fish Stocks* for instance would put the score at the exact opposite end of the performance spectrum and at a very poor environmental performance. To fix this problem and keep all high scores on the same end of the performance scale, an inversion of the latter dataset could be used by taking the scores and subtracting them from 1 to invert them (Hsu et al. 2013; A. Hsu et al. 2014). A very useful overview can be found at http://archive.epi.yale.edu/files/epi_methodology_infographic.pdf.

3.2.5. DATA CONVERSION TO INDICATORS

The raw data sets are now ready for application in the final step of indicator construction. This creates a common unit of analysis and makes it possible to compare all the indicators to each other. It also enables the indicators to be aggregated into a composite index. To achieve this, a proximity-to-target methodology is used. The indicator scores are calculated by applying raw data to the following generic formula:

$$\frac{\text{International range } - |\text{Target} - \text{Actual value}|}{\text{International range}} \times 100 \qquad (2)$$

The proximity-to-target methodology measures "*each entity's performance on any given indicator based on its position within a range established by the lowest performing entity (equivalent to 0 on a 0-100 scale) and the target (equivalent to 100)*" (Hsu et al. 2013).

3.3. WEIGHTING AND AGGREGATION

3.3.1. WEIGHTING SCHEME

Weighting is defined as *"converting and possibly aggregating indicator results across impact categories using numerical factors based on value choices*" by the ISO14042 standard (2001) for life cycle assessment (LCA) frameworks (Zhou & Schoenung 2007). The EPI combines several indicators into one comprehensive index. This requires aggregating all the individual indicator scores into one composite performance score, by numerically weighting each one of them according to two main criteria: The underlying dataset quality, and the degree of relevance the indicator has on assessing the policy issue. reduce (A Hsu et al. 2014c; Wu 2014). Thus, weights can be redistributed to reduce significance of a low quality data set by lowering the weighting. Weights can also be adjusted to highlight issues of relative importance by increasing the related indicators weight. (Hsu et al. 2013) The weights given to each of the main objectives are distributed 40%-60%, to *Environmental Health* and *Ecosystem Vitality* respectively in the EPI (see Table 5). This is done to compensate for the underlying variance of the scores and to achieve a 50%-50% distribution between the two objectives (A Hsu et al. 2014b). The difference between them indicates a lower variability across countries for *Ecosystem Vitality* (Hsu et al. 2013).

For composite indices the choice of weights and aggregation methods are sensitive and subjective. There is a lack of consensus in the scientific community about how to best determine which methodological strategy to use when combining issues of dissimilar natures and the choice of weights depends on both value system and preference structure. In the EPI, weight are established according to expert recommendation in addition to the aspects of data quality and relative issue importance in addition to how well the indicator measures environmental performance (Hsu et al. 2013).

3.3.2. AGGREGATION

The weighting and aggregation algorithms were deducted recreated based on the data provided in the data file "*2014_epi_framework_ indicator_ scores_friendly_0"* available at http://epi.yale.edu/downloads. The file contains the 2014 EPI index scores as well as the individual indicator, issue category and objective scores for each country. The statistical weightings are provided in the data sheet "*2014epi_weightings.xls*" available at http://epi.yale.edu/files/2014epi_weightings.xls, and rendered in Table 5.

The 2014 EPI is divided into three main levels of aggregation depicted in Figure 1. The size of the slices in the pie chart represent the respective weightings received by the indicators, issue categories and objectives (Wu 2014). The outer level consists of the indicators which are combined into the middle level i.e. the issue categories. The issue categories are combined to form the two main objectives of the inner level, which together make up the final index.

In general, the same generic formula is applied to aggregate the scores from each level:

$$\frac{Score}{100\%} \times Weighting \tag{3}$$

Starting with the indicator level, all indicators within one issue category generally receive an equally distributed weighting (Hsu et al. 2013). The total weighting of the indicators in one issue category always amounts to 100 %, so the total percentage divided by number of indicators yields the weighing of each one. E.g. an issue category consisting of three indicators means results in a weighting of 33% for each. The issue category scores are then calculated by applying Equation (3) to each indicator and adding them together.

The exception to this equal distribution is the *Climate and Energy* issue category where the *Trend in Carbon Intensity* and *Change of Trend in Carbon Intensity* receive special weights based on each country's GDP. Wealthier countries are scored with a higher weighting on the first indicator, while lower-income countries are scored with higher weighs on the latter indicator (A Hsu et al. 2014c). However, they are applied to Equation (**3**) in the exact same way as described above. The specific weightings are found in the file "*climate_indicators_weightings.xls*" in the "*2014 EPI Raw Data Files"* folder available at http://epi.yale.edu/downloads.

The issue category scores are combined into objective scores following the same calculation principle as for the indicators, and similarly for combining the objective scores into the total index scores (i.e. summing the weighted scores). However, in some cases this general calculation is not directly applicable due to missing score values caused by the materiality filters. Depending on different variables and criteria unique to each country, a materiality consideration is incorporated. The materiality is used to distinguish between which issues and indicators are relevant to each country. The EPI applies materiality filters to "level the playing field between countries so that they can be more consistently compared to one another. (…). If a country does not meet the necessary criteria for an indicator to be material to it, the indicator is not included in calculations of the country's score, and other indicators are given proportionally greater weights"(A. Hsu et al. 2014). As an example, for countries with no coast line, the Fisheries issue category is irrelevant and the affected countries are not scored in the indicators of this issue category (Telnes 2015). The full overview of materiality filters can be found in Appendix C.

A country that does not meet the materiality threshold of a given indicator or issue category is not scored and thus not included in the calculation. In consequence, the remaining indicators of the relevant category receive proportionally greater weight (A Hsu et al. 2014c). This results in Equation (**3**) undergoing a slight alteration to accommodate for the missing value(s).

$$\frac{Score}{Sum\ of\ remaining\ weights} \times Weighting \tag{4}$$

The weighting of the denominator in Equation (4) is the sum of the remaining weights after deducting the non-scored indicator weighting(s) from the original total of 100%. Then, like before, the resulting scores are added together. As an example, the landlocked countries are not scored in the *Fisheries* issue category which accounts for 10% of the total weights in the *Ecosystem Vitality* objective. This means that the new total weight now becomes 100% - 10% = 90%, and each indicator score is thus divided by 0,9 and multiplied by its original weighting. The individual weighted scores are then summed as before to obtain the objective score.

Table 5: The detailed statistical weightings of the 2014 EPI represent percentages of the level of aggregation, not the percentage of the overall EPI (A. Hsu et al. 2014). Data source available at http://epi.yale.edu/content/indicator-issue-and-objective-weightings.

Objective*	**Issue Category****	**Indicator****
Environmental Health (40%)	Health Impacts (33%)	Child Mortality (100%)
	Air Quality (33%)	Household Air Quality (33%)
		Air Pollution - Average Exposure to PM2.5 (33%)
		Air Pollution - PM2.5 Exceedance (33%)
	Water and Sanitation (33%)	Access to Drinking Water (50%)
		Access to Sanitation (50%)
Ecosystem Vitality (60%)	Water Resources (25%)	Wastewater Treatment (100%)
	Agriculture (5%)	Agricultural Subsidies (50%)
		Pesticide Regulation (50%)
	Forests (10%)	Change in Forest Cover (100%)
	Fisheries (10%)	Coastal Shelf Fishing Pressure (50%)
		Fish Stocks (50%)
	Biodiversity and Habitat (25%)	Terrestrial Protected Areas (National Biome Weights) (25%)
		Terrestrial Protected Areas (Global Biome Weights) (25%)
		Marine Protected Areas (25%)
		Critical Habitat Protection (25%)
	Climate and Energy (25%)	Trend in Carbon Intensity (weighting varies according to GDP)***
		Change of Trend in Carbon Intensity (weighting varies according to GDP)***
		Trend in CO2 Emissions per KWH (33%)
		Access to Electricity (N/A) *NOT USED FOR CALCULATION OF EPI SCORE

* These weightings do not reflect a preference for Ecosystem Vitality over Environmental Health, but rather reflect the underlying variance of the scores to achieve a 50-50 correlation of each objective score to the overall EPI score.

**Weightings may vary depending on whether an indicator is included for a country.

*** See: http://epi.yale.edu/content/climate-indicators-detailed-weightings

3.4. EXIOBASE Account data and Calculation Methodology

3.4.1. Data sources of the EXIOBASE v3

According to the article currently under review by Stadler et al. 2017 on the development of EXIOBASE v3, the approach used in creating the emission accounts is similar to the approaches used in previous EXIOBASE versions (Tukker & Dietzenbacher 2013; Wood, Stadler, Bulavskaya, Lutter, Giljum, de Koning, Kuenen, Schütz, Acosta-Fernández, Usubiaga, Simas, Ivanova, Weinzettel, J. Schmidt, et al. 2015) (Stadler et al. 2017). Only the main data sources will be listed here. For further information on data development and data sources of the EXIOBASE v3 the reader is referred to (Wood, Stadler, Bulavskaya, Lutter, Giljum, de Koning, Kuenen, Schütz, Acosta-Fernández, Usubiaga, Simas, Ivanova, Weinzettel, J. Schmidt, et al. 2015; Tukker & Dietzenbacher 2013; Stadler et al. 2017).

Table 6: Data sources of the EXIOBASE v3 account data (Stadler et al. 2017).

EXIOBSE v3 data accounts		Source
Energy accounts		The International Energy Agency (IEA).
Emission accounts	Air emissions	TEAM-model (Pulles et al. 2007).
	Combustion	Energy use data is combined with emission factors obtained from the TEAM model. International Energy Agency (IEA 2013).
	Non-combustion	"*Non-combustion activities, activity data are collected from various sources (e.g. UN Statistics, USGS, BGS, FAOSTAT, etc.)*" (Stadler et al. 2017)
Material	Fisheries	WU Global Material Flow Database (WU 2015).
	Fodder crops, grazing and crop residues	AgroSAM database (Müller et al. 2009).
Water		Agricultural water consumption: data-set building on (Pfister et al. 2011)(Pfister & Bayer 2014) the Water Footprint data-set (Mekonnen & Hoekstra 2011) based on FAO data. Industrial water use and water consumption: WaterGAP model (Flörke et al. 2013).
Land accounts		FAO online database and single, specific data sources. (Wood, Stadler, Bulavskaya, Lutter, Giljum, de Koning, Kuenen, Schütz, Acosta-Fernández, Usubiaga, Simas, Ivanova, Weinzettel, J. Schmidt, et al. 2015) The land-use extension statistical data : FAOSTAT (2014) (Stadler et al. 2017)
Waste		(UNDESA 2013; Schmidt et al. 2012)
Labour		International Labour Organization (ILO)'s LABORSTA, ILOSTAT databases (ILO 2014) (ILO 2013) and OECD's Statistics (OECD 2014).

3.4.2. Calculation Methodology Of The EXIOBASE

The EXIOBASE is calculated using an environmentally extended MRIO which calculate footprints by allocating production-based impacts to final use and adding the direct impacts (e.g. household production-based and household emissions of CO_2) (Usubiaga & Acosta-Fernández 2015). This approach is an extension of the standard IOA framework. The IOA is based on a monetary flow balance where the total output x of each sector equals the sum of total intermediate consumption Ax, final consumption y and total exports e subtracted by the total imports m (Peters 2008).

$$x = Ax + y + e - m \tag{5}$$

The x, y, e and m are vectors, while A is a matrix representing the intermediate consumption reflecting what inputs the domestic industries (represented by the rows) require form both domestic production and imports of the industries in the columns. Equation (**5**) represents the accounting balance of monetary flows for one region, but the relation holds for all regions. (Peters 2008; Davis & Caldeira 2010).

The MRIO methodology is, based on economic inputs and output of a country or a region. Equation (5) is represented in matrix form by Equation (6) (Peters 2008):

$$\begin{pmatrix} x^1 \\ x^2 \\ x^3 \\ \vdots \\ x^m \end{pmatrix} = \begin{pmatrix} A^{11} & A^{12} & A^{13} & \dots & A^{1m} \\ A^{21} & A^{22} & A^{23} & \dots & A^{2m} \\ A^{31} & A^{32} & A^{33} & \dots & A^{3m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A^{m1} & A^{m2} & A^{m3} & \dots & A^{mm} \end{pmatrix} \begin{pmatrix} x^1 \\ x^2 \\ x^3 \\ \vdots \\ x^m \end{pmatrix} + \begin{pmatrix} \sum_r y^{1r} \\ \sum_r y^{2r} \\ \sum_r y^{3r} \\ \vdots \\ \sum_r y^{mr} \end{pmatrix} \tag{6}$$

The interactions between different regions are represented by the A^{rs} matrices where trade between industries is happening from region r to region s. The diagonal A^{rr} matrices represent the domestic IO coefficients of interindustry requirements of a specific region r. Trade to final consumers in region s from region r industries is represented by y^{rs} (Hertwich & Peters 2010; Peters 2008).

The output can be expressed as a function of demand

$$x = (I - A)^{-1}y = Lx \tag{7}$$

where the L is the Leontief inverse and I is the identity matrix (Tukker et al. 2013). Since each economic activity can potentially cause environmental pressures, the output vector x can be multiplied by a stressor matrix F [denoted S here] to calculate the embodied environmental impacts S [denoted F here] (footprints) of domestic consumption (Hertwich & Peters 2010; Huijbregts et al. 2007). The S matrix represents the environmental extensions (stressor coefficients) or total impacts (e.g. CO2-emissions) per unit output x and can be expressed as F/x (Skelton et al. 2011). In reference to the above, this translates to F + Fy for the regional footprints, where Fy are the household impacts.

$$F = S(I - A)^{-1}y = S * L * y \tag{8}$$

The impacts embodied in trade can be accounted for since the MRIO "*distinguished between trade that goes to intermediate and final consumption*" (Peters 2008). This is one of the strengths of the MRIO approach, as it accounts for embodied emissions of trade caused by the indefinite need for imports in each level of the production chain (e.g. consumption of a car in Norway relies on production of parts in Germany, which again relies on imports from China which also relies on imports for their production) (Peters 2008).

The environmental impacts can be calculated using either a final production vector or a final consumption vector. Both apply the basic setup of Equation (8), however the y changes between the two. For the domestic environmental impacts (production-based accounts of the EXIOBASE) the y is divided into final domestic and export demands for the given region, while for the footprints (i.e. consumption-based accounts) the y is replaced by a consumption vector containing the final consumption of imports from all considered regions and the final consumption produced domestically (Davis & Caldeira 2010; Peters 2008).

3.5. CREATING A CONSUMPTION BASED INDEX

The goal of this thesis is to create a consumption-based environmental index through substituting the previously selected 2014 EPI indicators presented in the *Introduction* chapter with indicators calculated using the EXIOBASE v3 database. Following the suggestions in Table 1 - Table 4, nine of the 20 indicators are eligible for CBA adaptation. Only 44 of the 178 countries included in the EPI are considered for the alternative index dictated by the EXIOBASE country selection. By consulting the 2014 EPI methodology and indicator measurement characteristics, the appropriate EXIOBASE substitutions can be derived.

3.5.1. PROPOSING AN ALTERNATIVE INDEX

The alternative EXIOBASE indicators are constructed through the combination of stressors of a common unit that best reflect the environmental impact sought to be measured by the EPI. The unit of measurement and the calculation methodology, in addition to the scope of the data used in the calculation of the EPI, are investigated to develop the EXIOBASE indicators. The EXIOBASE includes a large number of stressors. In order to find the best fit for the original EPI, the indicator development was done in a circular process where the EXIOBASE indicators were calculated using various potential stressors. The EXIOBASE is firs calculated using production-based accounts to better compare it to the EPI methodology. However, since some indicators had a limited number of stressors to choose from, this was not always necessary. The considered stressors are mentioned but not elaborated on in the following. Only the results of this process for each indicator is presented in detail. The results of the circular evaluation were compared to the EPI to determine the best stressor combination based on scores and rankings for the year 2011. The indicator proposition and calculation methodology were thus developed in parallel. In accordance with this approach, the alternative consumption-based indicator development is presented as a combination of proposing an alternative index, and calculating the alternative indicators.

3.5.2. DEVELOPMENT OF THE EXIOBASE INDICATORS

The nine EPI 2014 indicators stem from five different issue categories, where only one is from the *Environmental Health* objective. The nine indicators are condensed into six EXIOBASE equivalents modelled after the indicator development methodology of each EPI 2014 indicator.

The EPI 2014 methodology is followed as closely as possible in order to diminish the impact of switching from one methodology to another. However, the data available from the EXIOBASE does not exactly match the data used by the EPI 2014, which limits how closely the EPI 2014 methodology can be followed. Due to the inevitable differences in data sets and methodology, deviations in the resulting index scores are expected. These issues will become clear in the detailed description of each indicator development that follows.

3.5.3. GENERAL METHODOLOGY

The EXIOBASE indicators are developed with two main goals in mind; replicating the EPI as closely as possible, and making the indicator calculation applicable with both the PBA and CBA accounts. Both counts are meant to diminish methodology interference on the results. Achieving these goals, considering the gaps and ensuing methodology differences between the EPI and the EXIOBASE, is not a straightforward procedure. Simplifications are necessary, and result in a generalized methodology that is applicable to all the indicators yet still follows the indicator development steps of the EPI.

3.5.4. TARGETS

The EPI methodology is based on a proximity-to-target score calculation that relies on setting distinct targets (high performance benchmarks (HPB)) and low performance benchmarks (Hsu et al. 2013). The targets are determined using expert opinion (or benchmarks set by organisations like the World Health Organization (WHO) and the low performance benchmarks (LPB) are set using the lowest performer or a 95th percentile Winsorization approach (Hsu et al. 2013).

However, the metadata methodology description for each indicator does not seem to be following the standard Winsorization method where raw data sets with tails at their minimums and maximums are set to a chosen percentile (95th in this case). Using the *Fish Stocks* indicator as an example, it becomes clear that the LPB set at 0,2 % is indeed derived from a regular 95th percentile and not the Winsorian 95th percentile (which would imply taking the 2,5th percentile on each end of the data set). This implies that the EPI is inconsistent in following its own target methodology (this could be a result of the "Measuring Progress: A Practical Guide From the Developers of the Environmental Performance Index (EPI)"(Hsu et al. 2013) mainly describing the EPI 2012, and possible changes being made in the 2014 edition. On the other hand, it is the only comprehensive methodology document referred to by the EPI 2014 and should thus be a valid source). In light of this, a combination of the methodology in the *Metadata* and the methodology of the *"Measuring Progress: A Practical Guide From the Developers of the Environmental Performance Index (EPI)"*(Hsu et al. 2013) will be used in the development of the EXIOBASE indicators. A 95th percentile is applied to indicators with raw data outliers, however, the outliers are not trimmed but replaced by the 95th percentile. This yields a zero score for all countries outside the 95th percentile. The raw data distribution plots for 2011 found in Appendix A provide a visualization of the presence of outliers. These plots were consulted when determining the necessity of applying a Winsorization at the 95th percentile. They show that there are clear outliers present in all raw data sets except for the *Carbon Intensity* indicator.

The criteria the HPB expert opinions are based on are not always specified by the EPI methodology, leaving the choice of EXIOBASE indicator targets open to interpretation. A general principle of using the dataset's best and worst performer as targets is thus applied for all indicators. The term dataset is referring to the calculated values obtained when arriving at the indicator unit if measurement. I most cases, the worst performer is an outlier and the LPB is determined by applying the modified Winsorization method just described. A more detailed target evaluation for each EXIOBASE indicator is found in the individual indicator developments that follow.

One may argue that using the best and worst performer is an oversimplification compared to the detailed targets set by the EPI 2014, but since a target that fits the PBA might not be adoptable in the CBA context this was deemed the best way forward. Using the top and bottom performer provides a target methodology that translates to both accounting schemes, while simultaneously avoiding changing the calculation methodology between the PBA and CBA.

Another issue arising with the setting of targets is that using only the best performer will result in only one country getting the full score of 100 points, and vice versa for the worst performer. This is important to keep in mind, as it can result in score differences that affect the comparability of the results.

3.5.5. LOGARITHMIC TRANSFORMATION

An important part of developing the EXIOBASE indictors is deciding whether or not to use a logarithmic transformation. As previously described, logarithmic transformations are applied by the EPI whenever datasets are skewed or are abnormally distributed (Hsu et al. 2013). Additionally, the EPI provides an alpha value to avoid zeroes when the logarithmic transformation is applied. The origin of these alpha values is not available in the descriptive material about the EPI 2014 making it difficult to reapply similar considerations in the EXIOBASE indicators. However, the use of alpha values has not been required in the alternative indicator development and is thus not further considered here.

Deciding whether to use the logarithmic transformation or not should in theory be determined by the nature of the raw data distribution, as suggested by the EPI methodology. In order to decide whether to use the logarithmic transformation or not, a Q-Q plot test is used. The Q-Q plots (available in Appendix D) reveal that all the EXIOBASE raw data sets are abnormally distributed, and should be logarithmically transformed. However, the use of discretion might be necessary since the final index scores depend on the individual indicator scores. If the deviations between the country scores of the EPI and the PBA become too large, the country comparison is compromised. Ultimately, the raw data set that yields the PBA indicator scores closest to the EPI scores is chosen regardless of the nature of the distribution. As will be seen, the logarithmic transformation yields the PBA scores closest to the EPI scores for all but one issue category. In addition, since the use of logarithmic transformation does not affect the ranking, such individual adjustments are justifiable.

3.5.6. MATERIALITY

The materiality considerations introduced in connection to the EPI weighting methodology are used to distinguish between which issues and indicators are relevant to each country. The materiality is also considered when proposing the alternative EXIOBASE indicators, and based on the grounds for applying it, they are included for the PBA indicators whenever suitable. The choices are justified further for the relevant indicators in the next section. The materiality is only applicable to the equivalent PBA indicators since they are based on country specific characteristics. In the CBA calculation the indicators are not subject to the same limitations and country criteria. For instance, a landlocked country may still import products from fishery activities and thus merit being scored regardless of domestic fishing activity.

3.5.7. DENOMINATORS AND TRENDS

While the EPI converts most of its indicators into a unitless scale (reflected in Appendix F) to construct the index in accordance with (de Sherbinin et al. 2013), the alternative indicators calculated using EXIOBASE are constructed by standardization using denominators of either population or Gross Domestic Product Purchasing Power parity (GDP PPP). This was necessary for comparability between the PBA and the CBA calculations. Population was used for all indicators except for the Climate and Energy which use the GDP PPP in line with the methodology of the EPI. It is worth noting that the latter approach is adopted in the 2016 edition of the index (EPI 2016) which is using "*comparable performance indicators, which requires standardizing raw values according to population, land area, gross domestic product, and other common units of measurement*" (Hsu 2016).

The GDP PPP converts GDP into international dollars using purchasing power parity rates usually extrapolated from 2011 International Comparison Program (ICP). The point is to provide a standard measure for comparison between countries based on real levels of expenditure since differences in price levels are not always evident from exchange rates. This way, the actual purchasing power can be compared across countries, and "*an international $ has the same purchasing power over GDP as the U.S dollar has in the United States*" (The World Bank Group 2016a).

Another difference is the use of trends in the EPI. Both the *Forests* and *Climate and Energy* issue category represent environmental impacts using trends. However, this practice is not conveyed to this study for two reasons. Firstly, using denominators as part of a trend calculation makes it difficult to tell which variable is causing the trend to shift. Secondly, the EPI is not clear enough in how the trends were calculated for the climate and energy issue category, making it difficult to precisely replicate the calculation process. In order to make all the indicators as comprehensible in their calculation as possible, the indicators using trends in the EPI are calculated using only the current year in the EXIOBASE. In addition, since a timeline is to be calculated as part of this study, it was not deemed sensible to include trends in the individual indicators.

3.5.8. ADJUSTED WEIGHTING FOR THE EXIOBASE

The weighting methodology of the original 2014 EPI will be transferred to the new index. Generally, this means that all substituting EXIOBASE indicators receive the same weighting as the original EPI indicator. If the EXIOBASE indicator is substituting more than one EPI indicator, the sum of the original EPI weightings becomes the total weight of the substitute. For instance, the indicator of the Forestry issue category is directly replaced by a single EXIOBASE indicator, which means that the weighting is kept as-is. For the *Air Quality* however, two of the EPI indicators are combined into one assigning the EXIOBASE with the total weighting of the two original ones. An overview of the EXIOBASE indicators and the adjusted weightings are found in Table 8.

3.6. ALTERNATIVE INDICATOR DEVELOPMENT BY EPI ISSUE CATEGORY

The section gives an overview of how the alternative EXIOBASE indicators were developed which stressors were used and justifications of the choices. The methodology described in the previous sections will be applied in detail to the alternative indicators, and the indicator calculation is done using values for 2011 which is the most recent year both the EPI and the EXIOBASE have available data. The EPI methodology description, rationale for inclusion and data sources are found in the *Metadata* (A Hsu et al. 2014a) are considered when choosing the stressors. A condensed version extracted from the project thesis (Telnes 2015) can be found in Appendix F where the information relevant to the indicator development is included. The reader is referred to http://archive.epi.yale.edu/files/2014_epi_metadata.pdf for further information. For some of the EPI indicators, the data needed for the intended measurement may not be reflected in the available EXIOBASE stressors. The type of environmental pressures the EPI 2014 indicators seek to portray is then used to determine the best EXIOBASE stressors for addressing the same issue with alternative measurements. The stressors included in the characterizations of the EXIOBASE indicators are found in Appendix E. All stressor coefficients are set to 1. The normal quantile-quantile plots are available in Appendix D and the raw data distributions are found in Appendix A.

The data sources for the EXIOBASE stressors were described earlier in section 3.4.1. The other main data sources used in the alternative indicator calculation are extracted from The World Bank and the International Monetary Fund (IMF) with the National statistics Republic of China (Taiwan) website (available at http://eng.stat.gov.tw/mp.asp?mp=5) as a supporting data source for Taiwan to confirm the IMF data.

An overview of the methodological differences between the EPI and the alternative EXIOBASE indicators is displayed in Table 7. The EPI indicators are lined up with their EXIOBASE equivalents allowing for comparison between their respective units, logarithmic transformation approach and LPBs.

Table 7: Overview of the methodological differences between the 2014 EPI and the alternative EXIOBASE indicators with respect to units, logarithmic transformation and targets used. Units for the 2014 EPI were extracted from the Metadata (A Hsu et al. 2014a). WHO = World Health Organization, env. = environmental, * = GDP PPP (current international $).

Issue category	Air Quality		Agriculture	Fisheries		Forests	Climate and Energy		
2014 EPI indicators	Air Pollution Avg. Exp. to PM2.5	Air Pollution PM2.5 Exceedance	Agricultural Subsidies	Fish Stocks	Coastal Shelf Fishing Pressure	Change in forest cover	Trend in carbon intensity	Change of Trend In Carbon Intensity	Trend in CO2 Emissions per kWh
Unit	$[\mu g]/[m^3]$	%	%	Fraction	$\frac{[Tonnes]}{[km^2]}$	%	kg / GDP PPP converted into a trend	kg / GDP PPP converted into a trend	kg / kWh per GDP PPP converted into a trend
Logarithmic transformation	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Target method (HPB/LPB)	WHO recommendation / Data set's lowest performer	Goal of zero exposure / 1st percentile	Goal of zero env. pressure / Not specified	Goal of zero overexploitation / 95th percentile	Not specified / 95th percentile	Goal of zero forest loss / 5th percentile	Not specified	Not specified	Not specified
Target source	WHO	WHO	Expert opinion	Expert opinion	Expert opinion	Expert opinion	Expert opinion	Expert opinion	Expert opinion
EXIOBASE indicators	PM2.5 Average Exposure		Agricultural Land Use	Marine Catch		Forestry Land Use	CO_2 Intensity		CO_2 Intensity per kWh
Unit	$\frac{[kg]}{\left[\frac{capita}{km^2}\right]}$		$\frac{[km^2]}{capita}$	$\frac{[kt] \times 10^6}{capita} = \frac{[kg]}{capita}$		$\frac{[km^2]}{capita}$	$\frac{[kg]}{[\$]^*}$		$\frac{[kg]}{[\$]^* \times [kWh]}$
Logarithmic transformation	No		Yes	Yes		Yes	Yes		Yes
Target method (HPB/LPB)	Best performer / 95th percentile		Best performer / 95th percentile	Best performer / 95th percentile		Best performer / 95th percentile	Best performer / Worst performer		Best performer / 95th percentile

3.6.1. AIR QUALITY ISSUE CATEGORY

EXIOBASE INDICATOR - PM2.5 Average Exposure

Indicator unit: kg PM2.5 / (capita/km^2).

Target and LPB method: Best and worst performer principle applied. The presence of outliers in the raw data set resulted in the application of the modified Winsorization approach at the 95th percentile.

Data sources:

- EXIOBASE emission accounts.
- The World Bank (The World Bank Group 2016d) provides the population density for all countries except Taiwan and the data was filtered to only include relevant countries and years.
- The national statistics for Taiwan's land area are extracted from the National Statistics Republic of China (Taiwan) https://eng.stat.gov.tw/mp.asp?mp=5 (National Statistics Republic of China (Taiwan) 2016a). The data was from the file "*01-01-01 Land, agricultural land and forest land areas (CSV)*" downloaded at http://eng.stat.gov.tw/lp.asp?ctNode=6341&CtUnit=1072&BaseDSD=36&mp=5 (date accessed 12/12-2016). The area is given explicitly for 2006 - 2011, yet between 2001 and 2005 only the 2001 value is given. The 2001 data was interpreted to be valid for all years between 2001 and 2005 since the 2001 and 2006 values were identical.
- Taiwan's population data was extracted from the IMF (International Monetary Fund 2013a).

Transformation need: According to the EPI methodology, raw data sets of abnormal distribution should be logarithmically transformed. The normal quantile-quantile plot (Appendix D) for the *PM2.5 Average Exposure* raw data set shows an abnormal distribution. However, the logarithmically transformed data yields score values that deviate from the EPI scores to such a degree that they negatively affect the comparability between the two methodologies. In this particular case, the abnormal distribution is kept and applied in the score calculation which results in a better match with the 2014 EPI scores.

Chosen stressors: PM2.5 (combustion and non-combustion) [kg] released into air.

See Appendix E for complete list of stressors and characterization coefficients.

Materiality transferred from the EPI: Not applicable.

Proposition /characterization:

The two air pollution indicators of the 2014 EPI both measure human health impacts related to exposure to PM2.5, but at different levels of exposure and with different units. The EXIOBASE provides 48 stressors for PM2.5 as well as stressors for other components linked to respiratory effects on humans (e.g. CO, NH_3 and SO_x). These are combined into two characterizations readily available in the EXIOBASE v3: ('*Particulate matter/Respiratory inorganics midpoint|kg PM2.5-eq|ILCD recommended CF|emission-weighed average PM2.5 equivalent*' and '*Particulate matter/Respiratory inorganics endpoint|DALY|ILCD recommended*

CF|Disability Adjusted Life Years (DALY)') (European Commission - Joint Research Centre & Institute for Environment and Sustainability 2012; Stadler et al. 2017).

Based on the available stressors and the similarity of the two EPI indicators' rationale for inclusion and measurement, the proposed indicator combines the two EPI indicators into one EXIOBASE indicator characterized by adding the stressors for PM2.5 from combustion and non-combustion. This yields the total characterized impact per country in kg.

The EPI uses a detailed satellite measurement of PM2.5 and a population grid that differentiates between population densities in different areas of a country. The difficulties involved in recreating the EPI calculation resulted in the proposed EXIOBASE characterization being divided by the average population density (total population divided by total land area of each country). In other words, the population density measurement is not as detailed as that of the EPI, but it is the closest approximation to the EPI 2014 methodology. This is a source of score deviation between the two methodologies. The population density is extracted from the World Bank for all countries except for Taiwan whose population is provided by the IMF, and divided by the land area provided by the *Statistical Yearbook Of The Republic Of China* (National Statistics Republic of China (Taiwan) 2016a).

The score calculation method is largely based on the *Air Pollution – PM2.5 Average Exposure* indicator due to its resemblance to the available EXIOBASE characterization. The EPI uses a target set by the WHO expressing the level of exposure that is harmful to humans. However, this target is measured in a different unit than what is available for the proposed EXIOBASE indicator whose unit is given in kg PM2.5 per population density, while the EPI measurement includes an additional spatial dimension ($\mu g/m^3$). A different target is thus needed. In addition, the raw data distribution of the proposed indicator show presence of outliers. The proposed indicator targets were thus set using the best performer and the modified Winsorization approach at the 95th percentile.

When tested for normality, the distribution of the resulting scores showed that, according to EPI methodology, a logarithmic transform should be used to correct for skewedness. However, this causes scores deviations between the EPI and the proposed indicator resulting in such large shift in country performance between the two making them too deviant for comparison (top performers shifted to low performers). The untransformed values match the EPI better keeping the score distribution in the same range as the EPI scores, also because the EPI has many countries scoring 100 which is not possible to achieve with the PBA due to the target methodology. For this particular indicator the normal distribution was thus applied despite the results of the Q-Q plot because of its superior fit with the EPI scores. The score comparison was done by multiplying the two EPI indicators by their respective indicator level weightings (33 % each) and multiplying the EXIOBASE indicator by 66 % in order for them to be equivalent.

No materiality was used for this indicator.

3.6.2. AGRICULTURE ISSUE CATEGORY

EXIOBASE INDICATOR – AGRICULTURAL LAND USE

Indicator unit: km^2/capita.

Target and LPB method: Best and worst performer principle applied. The presence of outliers in the raw data set resulted in the application of the modified Winsorization approach at the 95th percentile.

Data sources:

- EXIOBASE v3 land use accounts.
- Population data extracted from The World Bank (The World Bank Group 2016c) and filtered to only include relevant countries and years.
- Taiwan population extracted from IMF (International Monetary Fund 2013a) supported by the National Statistic Republic of China (Taiwan) (National Statistics Republic of China (Taiwan) 2016b).

Transformation need: Logarithmic transformation using the natural logarithm was applied based on the results of the Q-Q plot and the methodology of the EPI 2014 where a log transformation was used.

Chosen stressors:

- Land use – Arable land (nine different crop types) [km^2]
- Land use – Permanent pasture [km^2]

See Appendix E for complete list of stressors and characterization coefficients.

Materiality transferred from the EPI: Not applicable.

Proposed characterization and score calculation:
The EPI indicator is a proxy attempting to measure environmental impacts by looking at subsidies levels. The EXIOBASE does not include stressors for this precise measurement, but it does contain stressors that cover the environmental pressures related to agriculture. As explained in the rationale for inclusion, the EPI highlights a number of environmental pressures stemming from agriculture. A combination of the effects of ecotoxicity, land use in sensitive areas, and overexploitation of water and nutrients would be ideal. However, even though these pressures are individually reflected in the EXIOBASE database stressors, it is not possible to add them together due their difference in units. Thus, a single type of environmental stressor must be chosen.

Apart from the land use stressors, there are several others related to ecotoxicity, water use and eutrophication that could have been relevant for this indicator. A characterization like the *'Damage to Ecosystem Quality caused by land occupation (H.A)|PDF*m2*yr|ECOINDICATOR 99 (H.A)|Damage to Ecosystem Quality caused by land occupation (H.A)'* (Goedkoop & Spriensma 2001) could have been applied, but since it also measure pesticides, this would overlap the other indicator in the *Agriculture* issue category and is thus not used here. Moreover, water consumption could be applied, but since the land use and the water consumption don't have the same unit they cannot be combined into a common characterization. However, adding water consumption and/or eutrophication is something that is considered in the future work. In addition, the indicators of the agriculture issue category have the lowest weightings of all (1,5 % of the total 100 % weighting) due to the nature of the proxy measure. The impact of the indicator's score will therefore have a very limited impact on the total index score, and they choice of stressor becomes as much a question of preference.

Out of the four pressures highlighted, the farmland expansion was chosen for this study as a proxy for the agricultural subsidies indicator through the land use stressors. The land use was chosen based on the considerations above as well as its inclusion as one of the four main footprints investigate by Tukker et al. (2016) making it possible to subsequently compare the results to their findings (Tukker et al. 2016). Although the land use was chosen here, the water consumption could also have served as a proxy. This is suggested in the further work.

The EXIOBASE indicator is characterized by combining nine land use stressors for arable land covering nine different crop types, and one for land use by permanent pasture. The total land use (km^2) from these stressors is further divided by the total population of each country. The population was extracted from the World Bank (The World Bank Group 2016c) except for Taiwan. Taiwan data was downloaded from the National statistics Republic of China (Taiwan) website and from the IMF.

Since the proposed indicator proxy measurement is not related to the original EPI proxy, the targets were set using the general methodology for the alternative indicator development. Based on the raw data distribution and the Q-Q plot, the targets were set using the modified Winsorization at the 95th percentile and the best performer.

No materiality was applied to this indicator.

3.6.3. FORESTS ISSUE CATEGORY

EXIOBASE - FORESTRY LAND USE

Unit: km^2/capita.

Target and LPB method: Best and worst performer principle applied. The presence of outliers in the raw data set resulted in the application of the modified Winsorization approach at the 95th percentile.

Data sources:

- EXIOBASE v3 land use accounts.
- Population data was extracted from The World Bank (The World Bank Group 2016c) and filtered to only include relevant countries and years.
- Taiwan population extracted from IMF (International Monetary Fund 2013a) supported by the National Statistic Republic of China (Taiwan) (National Statistics Republic of China (Taiwan) 2016b).

Transformation need: Logarithmic transformation using the natural logarithm was applied based on the results of the Q-Q plot and the methodology of the EPI 2014 where a log transformation was used.

Chosen stressors:

- 'Used Forest Land - Industrial roundwood|nature|km2'
- 'Used Forest Land - Wood fuel|nature|km2'

Materiality transferred from the EPI: Malta is not given a score in the PBA calculation due to the materiality filter of the EPI. This materiality does not apply in the case of the CBA following the principles of this accounting scheme.

Proposed characterization and score calculation:
The EPI uses a trend representing the net forest gain between the years 2000 and 2012. The percentage in net gain is obtained by subtracting the forest loss from the forest gain and dividing this net gain by the total forest cover in 2000. The EXIOBASE, however, only considers the area of land used each year. Moreover, it does not provide the accumulative forest area remaining, nor the area used up until the year 2000. Translating the EPI measurement into the proposed EXIOBASE indicator would mean subtracting the land use in 2000 from the land use in 2011 and dividing by the total land use for each country to get a similar percentage. However, this only reflects the net loss in forest cover as portrayed through land use change in the 12-year period.

These differences make it difficult to achieve a measurement identical to that of the EPI, as only the loss relative to the total amount already lost would be measurable with the EXIOBASE. As previously explained, trend calculations are inconvenient for application to the proposed indicator framework due to the use of denominators and the difficulties related to establishing which variable is causing the change (changing population or changing forest cover). A trend calculation using km^2/capita for 2011 and for 2000 was contemplated and tested, but it was concluded that population changes made the resulting land use per capita trend too ambiguous for later analysis. Additionally, using a trend would interfere with the timeline calculation conducted later, thus the EXIOBASE indicator is measured per year.

The proposed indicator is characterized by combining the two stressors for used forest land measured in km^2 and calculated by diving the absolute measure by the population with provided by the World Bank, and the IMF supported by the National statistics Republic of China (Taiwan).

The EPI target is based on the percentage change in forest cover where a positive percentage signifies forest loss, and 0 % is a logical target giving negative changes a score of 100%. Since this does not apply here, the EXIOBASE scores are calculated using the general methodology described in section 3.5 and applies a modified Winsorization at the 95th percentile to exclude outliers based on the raw data distribution plot. The best performer is used for the HPB. The scores were then logarithmically transformed in accordance with the Q-Q plot.

Materiality is applied to Malta, which falls below the threshold of forest covered area necessary to be scored in this issue category. The materiality is transferred to the EXIOBASE PBA calculation, however, since imports are not affected by the materiality considerations, all countries are scored in the CBA calculation.

3.6.4. FISHERIES ISSUE CATEGORY

EXIOBASE INDICATOR – MARINE CATCH

Indicator unit: kg/capita.

Target and LPB method: Best and worst performer principle applied. The presence of outliers in the raw data set resulted in the application of the modified Winsorization approach at the 95th percentile.

Data sources:

- EXIOBASE v3 material accounts.
- Population data extracted from The World Bank (The World Bank Group 2016c) and filtered to only include relevant countries and years.
- Taiwan population extracted from IMF (International Monetary Fund 2013a) supported by the National Statistic Republic of China (Taiwan) (National Statistics Republic of China (Taiwan) 2016b).

Transformation need: Logarithmic transformation using the natural logarithm was applied based on the results of the Q-Q plot and the methodology of the EPI 2014 where a log transformation was used.

Chosen stressors:

- Unused Domestic Extraction - Fishery - Marine fish catch|kt|
- Domestic Extraction Used - Fishery - Marine fish catch|kt|
- Unused Domestic Extraction - Fishery - Other (e.g. Aquatic mammals)|kt|
- Domestic Extraction Used - Fishery - Other (e.g. Aquatic mammals)|kt|

Materiality transferred from the EPI: According to the EPI, the *Fisheries* issue category is calculated with the application of two materiality filters (*BadFish* and *BadEEZ*, see Appendix C). *BadFish* penalizes countries for insufficient or inadequate catch data, *BadEEZ* penalizes for insufficient or inadequate data for at least one of its Exclusive Economic Zones (EEZs). According to the *BadFish* materiality filter, the following countries should be given the lowest average score for a given year for the *Fish Stocks* and *Coastal Shelf Fishing Pressure* indicators: Belgium Bulgaria, Latvia, Lithuania, Malta, Romania and Slovenia. Making this distinction in the EXIOBASE data is not directly transferrable as it is basing its data on different data that are not necessarily affected by the same limitations as the data sources used by the EPI (see Appendix H for details on data sources). In addition, applying this materiality would render the comparability between the PBA and the CBA flawed since the consumption-based calculation is not affected by the materiality filter and all countries are given a score regardless of land lock and catch data status. These two materiality filters were thus excluded for the proposed indicator.

The following countries should be given the lowest observed value for EEZ according to the *BadEEZ* materiality filter: Australia, France, the Netherlands, Russia, the United Kingdom and the United States. Translated to the EXIOBASE it would mean using the lowest catch per person between 2002 and 2011 to calculate the scores for these countries. This is problematic because it means that the countries affected receive the same score across the entire time series (as is the case for the back-casted scores of the EPI). Although the goal of this thesis is to replicate the EPI as closely as possible, the use of this particular materiality will distort the dynamic comparability with the CBA later in the study. Also, although attempted at the start of the study, the EEZs are not applied to the proposed indicator calculation, and hence the application of this materiality is not followed here.

The only materiality filter that applies to both the EPI and the PBA is the *Landlock*, where land locked countries are not scored in the EPI. The same countries and sectors are set to zero in the EXIOBASE PBA account data. To replicate the PBA score, the countries were treated likewise, and thus not scored in for this issue category. As for forestry land use, the materiality filters do not apply to the CBA, and large artificial differences are expected for these countries between the PBA and CBA scores.

Proposed characterization and score calculation:
The EPI uses two indicators to portray the pressures from fishing activities, one measuring overexploitation, the other attempting to measure impacts from bycatch and fishing gear. The latter makes the use of dredging equipment as base for measurement of the damage done to ecosystems and caused by bycatch of other aquatic species not directly targeted by the fishing industry. The EXIOBASE has a limited selection of stressors measuring fishing activities, and the two EPI indicators are for this reason combined into one proposed indicator attempting to portray both the original measurements. The EXIOBASE includes stressors for both used and unused domestic extraction of aquatic plants, inland waters fish catch, marine fish catch and other catch types (e.g. aquatic mammals). The two first are not relevant for the measurement of the EPI, as it focuses on the marine catch of each country, and is not concerned with exploitation of aquatic vegetation. The marine fish catch is the closest related to the *Fish Stock* indicator, and the last one that measures catch of other species is considered a close proxy for the *Coastal Shelf Fishing Pressure*. Both the used and unused domestic extraction was included in order to account for both the intended catch and the bycatch (represented by the unused domestic extraction). The proposed EXIOBASE indicator is thus characterized by four stressors for both used and unused domestic extraction of marine catch and other aquatic species measured in [kt].

The EXIOBASE indicator is calculated by adding the stressors to obtain the total catch per country. The total catch is divided by each country's population using data extracted from the World Bank and the IMF with supporting data from the Chinese government for Taiwan. The unit is converted form kt/capita to kg/capita in order to make the magnitudes more suitable (using kt yields values to the power of minus five, which was found impractical).

While the EPI indicators seeks to measure the externalities resulting from the fishing industry, the EXIOBASE simply measures the absolute catch amount. In other words, the EXIOBASE lacks the appropriate unit of measurement to precisely replicate the EPI measurement of overexploitation. This is reflected in the setting of targets, where the EPI has a goal of zero overexploitation as its HPB, while the EXIOBASE is using lowest catch per person target. The latter results in the best performer having a catch level that may lie below a sustainable and economically viable catch amount, and could theoretically be set at a higher target level. The general methodology for indicator development is applied, and based on the raw data distribution plot, a Winsorization at the 95th percentile is applied. Based on the methodology of the EPI indicators and the result of the Q-Q plot, the scores were calculated using logarithmic transformation.

Materiality was applied as explained above.

3.6.5. CLIMATE AND ENERGY ISSUE CATEGORY

EXIOBASE – CO_2 intensity

Indicator unit: CO2/GDP PPP (current international $).

Target and LPB method: Best and worst performer principle applied. No distinct outliers in the raw data set.

Data sources:

- EXIOBASE v3 emission accounts.
- GDP PPP (current international $) data were extracted from The World Bank (The World Bank Group 2016a) and filtered to only include relevant countries and years.
- Taiwan GDP PPP data extracted from IMF (International Monetary Fund 2013a).

Transformation need: Logarithmic transformation using the natural logarithm was applied based on the results of the Q-Q plot and the methodology of the EPI 2014 where a log transformation was used.

Chosen stressors:

- 'CO2 - combustion - air|air|kg'
- 'CO2 - non combustion - Cement production - air|air|kg'

Materiality transferred from the EPI: Not applicable

Proposed characterization and score calculation:
The EPI measures the carbon intensity using two similar indicators that both portray trends in carbon intensity, where the only difference is the years the trends are based on. Because trends are not used for the proposed indicators, the *Trend in Carbon Intensity* and *Change of Trend in Carbon Intensity* indicators are substituted by one EXIOBASE indicator. The EPI indicators are measured by kg CO_2/GDP PPP (current international $) according to the metadata, however, the raw data file states using GDP PPP (constant year 2000 US dollars). The data used here is the data stated in the Metadata. According to the http://cait2.wri.org/docs/CAIT2.0_CountryGHG_Methods.pdf listed by the EPI *Metadata*, the CO_2 included is from fossil fuels and cement production. The proposed EXIOBASE indicator is thus characterization by the *CO2 non-combustion Cement production* stressor and the *CO2-combustion* stressor. Waste is not included as a source of CO_2 emission by the EPI source, thus it will not be included here. The other CO2 stressors ("*CO2 - agriculture - peat decay - air|air|kg*", "*CO2 - waste - biogenic - air|air|kg*", "*CO2 - waste - fossil - air|air|kg*" and "*CO2 - non combustion - Lime production - air|air|kg*") were excluded for the same reason.

The proposed EXIOBASE indicator is calculated by dividing the characterizations summed absolute value of kg CO2 by the same GDP PPP from the World Bank as in the *Metadata*. In other words, the units are exactly the same for the two methodologies, and the score results can be expected to be similar, except for the trend influence. The raw data distribution plot shows that there is no presence of outliers, and the best and worst performer is used as targets (HPB and LPB) for this score calculation. The Q-Q plot shows an abnormal distribution, and the data set is thus logarithmically transformed for the score calculation.

EXIOBASE – CO_2 Intensity per kWh

Indicator unit: kg / (GDP PPP current international $ * kWh).

Target and LPB method: Best and worst performer principle applied. The presence of outliers in the raw data set resulted in the application of the modified Winsorization approach at the 95th percentile.

Data sources:

- EXIOBASE v3 energy accounts and emission accounts.
- GDP PPP (current international $) data were extracted from The World Bank (The World Bank Group 2016a) and filtered to only include relevant countries and years.
- Taiwan GDP PPP data extracted from IMF (International Monetary Fund 2013a).

Chosen stressors:

The calculation requires two catheterizations from the EXIOBASE. The first characterization combines twelve different stressors for electricity production, where seven represent renewable alternatives, while the remaining are fossil, nuclear of not elsewhere classified.

- Energy Carrier Use Electricity by '*Type of energy production*' [TJ]

The second characterization consists of one stressor, and represents the CO_2 emissions.

- CO2-combustion- air|air|kg

See Appendix E for complete list of stressors.

Materiality transferred from the EPI: Not applicable.

Proposed characterization and score calculation:
The EPI is calculating the CO_2 intensity of electricity and heat production by different types of power generating technologies (thermal power plants, nuclear, hydro, waste, geothermal and all other renewables). The indicator is prone to data issues, and the scores are calculated using both trends and absolute measures depending on the country performance (A Hsu et al. 2014a). These distinctions are not specified in the EPI methodology, and the indicator calculation was not exactly reproducible (see Appendix F for details). Moreover, the data source is only available through purchase, and detailed information was thus unavailable. The EXIOBASE has distinct stressors for electricity use which are used to characterize the kWh part of the indicator calculation, while the CO_2 from combustion stressor is used for the emission part. This stressor covers all sectors, so ideally, only the CO_2 from the electricity sectors should have been included. This was done for 2011 to see if it was necessary, and the results showed little deviation between using CO_2 combustion from all sectors and the CO_2 only from electricity use (the countries with the largest score deviation between the two cases are Norway at 25,4 and Russia at 20,9 score points). Based on this, the CO_2 combustion for all sectors was thus used for simplicity.

The proposed EXIOBASE indicator is calculated by converting the electricity stressors measured in [TJ] to kWh by multiplying by $10^6/3,6$. The kg CO_2 is divided by the kWh and this is then divided by GDP PPP provided by the World Bank and the IMF. The raw data distribution and Q-Q plots result in the use of a Winsorization at the 95th percentile and a logarithmic transformation for the score calculation.

3.7. INFLUENCE SCORES

The so called influence scores were included to show the difference between the EPI, the PBA and the CBA score calculations, and to see how much each indicator influenced the total index score. Influence scores were calculated by multiplying the scores for each country in each indicator with the combined weighting of the indices (first for the original EPI, then with the adapted weightings for the PBA and CBA shown in Table 8). This enables a detailed overview of the influence of each country in each indicator. The general trend is made available by taking the average influence score of each indicator.

Table 8: The detailed statistical weightings of the 2014 EPI represent percentages of the level of aggregation, not the percentage of the overall EPI (A. Hsu et al. 2014). http://epi.yale.edu/content/indicator-issue-and-objective-weightings. The adjusted EXIOBASE weighting is shown in bold for each relevant indicator.

Objective*	**Issue Category****	**Indicator****	**Total weighting per indicator (%)**
Environmental Health (40%)	Health Impacts (33%)	Child Mortality (100%)	13,33
	Air Quality (33%)	Household Air Quality (33%)	4,44
		PM2.5 Average Exposure (66%)	**8,89**
	Water and Sanitation (33%)	Access to Drinking Water (50%)	6,67
		Access to Sanitation (50%)	6,67
Ecosystem Vitality (60%)	Water Resources (25%)	Wastewater Treatment (100%)	15
	Agriculture (5%)	***Agricultural Land Use (50%)***	**1,5**
		Pesticide Regulation (50%)	1,5
	Forests (10%)	***Forestry Land Use (100%)***	**6**
	Fisheries (10%)	***Marine Catch (100%)***	**6**
	Biodiversity and Habitat (25%)	Terrestrial Protected Areas (National Biome Weights) (25%)	15
		Terrestrial Protected Areas (Global Biome Weights) (25%)	
		Marine Protected Areas (25%)	
		Critical Habitat Protection (25%)	
	Climate and Energy (25%)	**Carbon Intensity (66%)**	**10**
		CO_2 Intensity per kWh (33%)	**5**
		Access to Electricity (N/A) *NOT USED FOR CALCULATION OF EPI SCORE	-

* These weightings do not reflect a preference for Ecosystem Vitality over Environmental Health, but rather reflect the underlying variance of the scores to achieve a 50-50 correlation of each objective score to the overall EPI score.

**Weightings may vary depending on whether an indicator is included for a country.

3.8. ANALYSIS OVER TIME: TREND LINES AND DECOUPLING

The alternative index is calculated over time using both production- and consumption-based account data for all 44 countries. However, the results are presented using three countries (China, Norway and the US) as examples of a developing country, a European developed country and a North American developed country. China and the US were chosen based on their status as important exporting and importing countries globally. Norway was chosen to represent Europe in addition to bringing an interesting addition to the two typical exporters and importers represented by the two others. Even though Norway is a highly developed country, it does not represent a typical developed European country, with its net export of materials embodied in trade (Tukker et al. 2014). In 2007 the US and China emitted 39% of all climate active gases. The highest carbon, water, land and material footprints per capita are found for high-income developed countries like the US and EU countries and the majority of net exports from China are consumed in Europe and the US (Tukker et al. 2014; Tukker et al. 2016). Data sources for GDP PPP (current international $) per capita used in the timeline calculation were extracted from The World Bank (The World Bank Group 2016b), and for Taiwan from the IMF (International Monetary Fund 2013b),

The results for the three countries are then evaluated and compared to the results of a paper currently under review on the EXIOBASE v3 by Stadler et al. 2017, as well as the general results of consumption-based vs production-based accounting presented in the *Theory* chapter. However, since this thesis is based on the 2014 EPI framework, environmental impacts are translated into scores instead of using absolute values, which means that the trend lines cannot be evaluated in the same way as absolute value impacts. This is because the target setting methodology gives the worst performer (country with highest absolute value) the lowest score, thus inverting the scale. Contrarily to the absolute value impact-slope relationship, where an increasing slope equals increased impact, the presence of a positive trend in the PBA or CBA scores is the equivalent of their environmental impacts decreasing (higher score equals enhanced environmental performance i.e. decreased environmental impact) and vice versa.

PBA score > CBA score = CBA impact > PBA impact: The country has a lower environmental impact from domestic production and export than from domestic production for domestic consumption and from imports due to the impacts embodied in trade (typical developed country).

CBA score > PBA score = PBA impact > CBA impact: The country has a lower environmental impact from domestic production for domestic consumption and from imports than from domestic production consumers and exports (typical developing country).

The decoupling is evaluated in a similar fashion, and the consideration of the three countries continues as examples representing trends for both developed and developing countries. The decoupling between environmental impacts and economic development is evaluated by plotting the production- and consumption-based index scores against the GDP PPP per capita (current international $). Signs of decoupling were evaluated based on the theory stating that decoupling is present when "*maintaining economic output while reducing the negative environmental impact of any economic activities that are undertaken.*" (Fischer-Kowalski et al. 2011) extracted from the associated factsheet to "*Decoupling natural resource use and environmental impacts from economic growth*" by the United Nations Environment Programme (UNEP) and the International Resource Panel (IRP). In other words, a levelling or decline of environmental impact relative to the economic growth would signify that economic development is happening without increasing the environmental impacts. This is ultimately the desired outcome. On the other hand, if the environmental impact is following the trend of the economic development they are not decoupled.

4. RESULTS

This section starts by presenting the results of the 2014 EPI reproducibility with respect to data sources, raw data and weightings. This is followed by an overview of the total weightings used in the influence score calculation that is presented next. In order to get a better impression of the consequences of adapting the EPI 2014 into a consumption based index and how the original and alternative methodologies differ the year 2011 is examined. The total index and the proposed indicators are investigated to uncover the differences between the EPI and the PBA scores, and between the PBA and the CBA scores. With these findings in mind, a further examination is conducted using three example countries (China, Norway and the US) to calculate all three calculation schemes (EPI, PBA and CBA) over time from the year 2002 to 2011. In addition the alternative index scores are compared to the economic development of the three aforementioned countries to decoupling considerations. However, since these comparisons are done for the total index scores, a more nuanced view on the alternative index is provided through the examination of the CO_2 Intensity indicator compared to the EXIOBASE v3 GHG impact results found by Stadler et al. (2017).

4.1. DERIVING THE 2014 EPI WEIGHTING AND SUMMATION ALGORITHMS

The 2014 EPI framework serves as a basis for the goal of this thesis, namely the development of a consumption based accounting index. In order to use it as such, the methodology and calculation approaches of the 2014 EPI are evaluated to check for any deviations or inconsistencies between the theory and the calculated results. This section attempts to recreate the 2014 EPI raw data and scores by following the methodology provided in the metadata overview "*2014 EPI - Indicator Metadata*" (A Hsu et al. 2014a), the "*Measuring Progress: A Practical Guide From the Developers of the Environmental Performance Index (EPI)*" (Hsu et al. 2013) and in the full report (A Hsu et al. 2014c). All mentioning of raw data files refer to the files found in the folder *2014 EPI Raw Data Files* available at http://epi.yale.edu/downloads.

There are two levels to reproducing the final scores: reproducing the raw data from the data sources, and calculating the scores from the raw data. Each individual indicator is evaluated following the 2014 EPI indicator calculation methodology, namely going through the following steps: *Data Preparation*, *Data Transformation* and *Data Conversion to Indicators*. The first level is presented under the subtitle *Data Preparation*, while the latter is described under *Data Conversion to Indicators*. During the investigation into the raw data development, it became apparent that this step was proving difficult due to the lack of detailed methodology descriptions available for several of the indicators. Especially the *Climate and Energy* indicators were prone to unclear methodology descriptions. The EPI developers were contacted for further explanation of the methodology (email correspondence can be found in Appendix G). Since the further tasks of this thesis are based on a selection of the EPI indicators, only these are explored in detail for this level. Moreover, the raw data and data sources of the indicators deemed ineligible for CBA conversion will remain unchanged from the original index to the alternative index, which makes a detailed investigation redundant to the final results. However, all EPI indicators are used in the alternative index score calculation, and it is therefore essential that the calculation methodology step from raw data to score is reproducible. All indicators are thus be thoroughly investigated for this level. The *Child Mortality* indicator is used as a data preparation example for the indicators that are not deemed relevant for CBA conversion. *Change in Forest Cover* is used as an example for the indicators that are used for conversion of CBA. The detailed investigation into each indicator is rendered in Appendix F. The main results are extracted from the individual investigation into the methodology and reproducibility of the 2014 EPI indicators and are presented below.

Reproducing the 2014 EPI index scores consists of two parts: recalculating the weighting algorithms and reproducing the summation algorithms producing the scores. The original 2014 EPI indicator and weighting data were downloaded from http://epi.yale.edu/downloads and extracted from the files "*2014_ epi_ framework_indicator_scores_froendly.xls*", "*2014epi_weightings_.xls*" and "*climate_indicators_weightings.xls*".

The result of using the weighting algorithms is presented in Figure 4. It shows the original 2014 EPI scores of the 44 countries included in the EXIOBASE in ranked order compared to the reconstructed score values obtained when applying the 2014 EPI weighting methodology. The scores match up almost perfectly and the small deviations are due to the EPI rounding off the scores to two decimals. The ranking is shown on the secondary axis to give an impression of their original placement and relative performance to each other. The general trend follows what is expected from a PBA index, where the developed countries (e.g. Norway and the United States (US) perform better than the developing countries (e.g. China and India). For simplicity, only the EXIOBASE selection of countries is shown here, although the weighting methodology is fully reproducible for all countries.

The only exceptions are found in the *Terrestrial Protected Areas* (*global and national biomes*) indicators. Whenever these two indicators are the only ones with values for a certain country, the *Biodiversity and Habitat* issue category score tends to be based on the national biome score instead of the weighted average. This affects two of the EXIOBASE countries (Austria and Slovakia) but the differences are minor (3,7 and 3,4 points). Additionally, Lithuania's score is slightly different, but does not use any of the indicator scores as a substitute and it is unclear why there is a deviation, although also relatively small (4,08 points). Since this issue category is not used for the EXIOBASE index (as will be discussed later) it is not considered problematic for the further results.

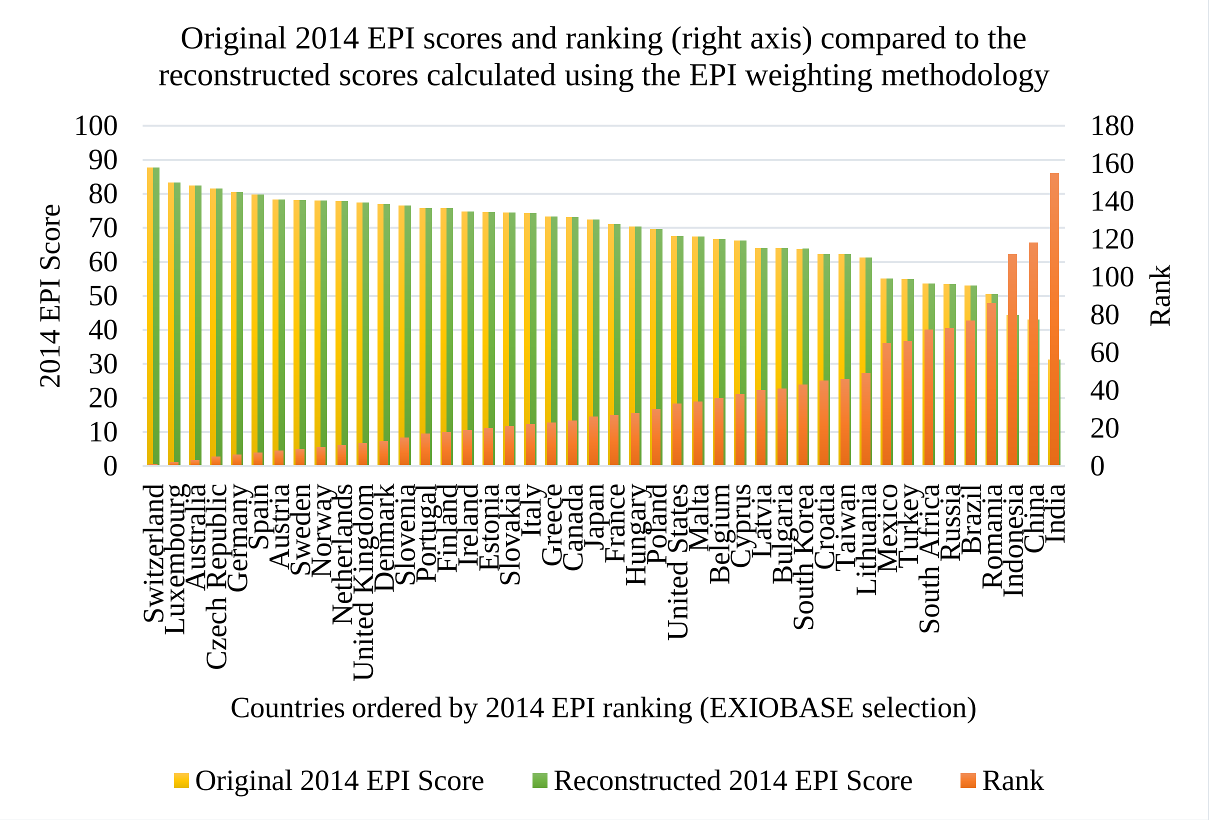


Figure 4: Comparison of the original 2014 EPI scores and the reconstructed score values using the 44 EXIOBASE countries. The ranking order according to the original 2014 EPI are shown on the right axis.

The next step consists of reconstructing the scores using the raw data provided. The same selection of countries as above is presented here, since these are the ones considered for the rest of the thesis. The remaining country scores will not be presented here, but they tend to follow the same level of reproducibility for all indicators. Some indicators were perfectly reproducible, others proved to have smaller deviations from the original scores, while a small number of indicators end up with larger differences. The two latter issues mainly concern the *Climate and Energy* indicators, which use an unspecified regression method. Dr. Angel Hsu of the EPI research team was contacted concerning the calculation issues, which helped clarify some of them. However, the *Trend in* CO_2 *Emissions per kWh* remains only partially recalculated.

Recalculation of the 2014 EPI by applying the methodology provided in the *Metadata* and the same weighting scheme as in Figure 4 yields the results presented in Figure 5. In general the recalculated scores are following the original scores almost exactly. The slight differences are caused by the indicators with noticeable deviations, namely the *Coastal Shelf Fishing Pressure* and the *Trend in Carbon Emissions per kWh*. In addition several of the indicators yield recalculated scores close to the original, but with minor deviations (e.g. *Access to Sanitation* and *Trend in Carbon Intensity*). The rounding to two decimals from the weighting step are still present contributing to the deviation, although this effect is marginal compared to the others. The reproducibility of each indicator is summarized in Table 9.

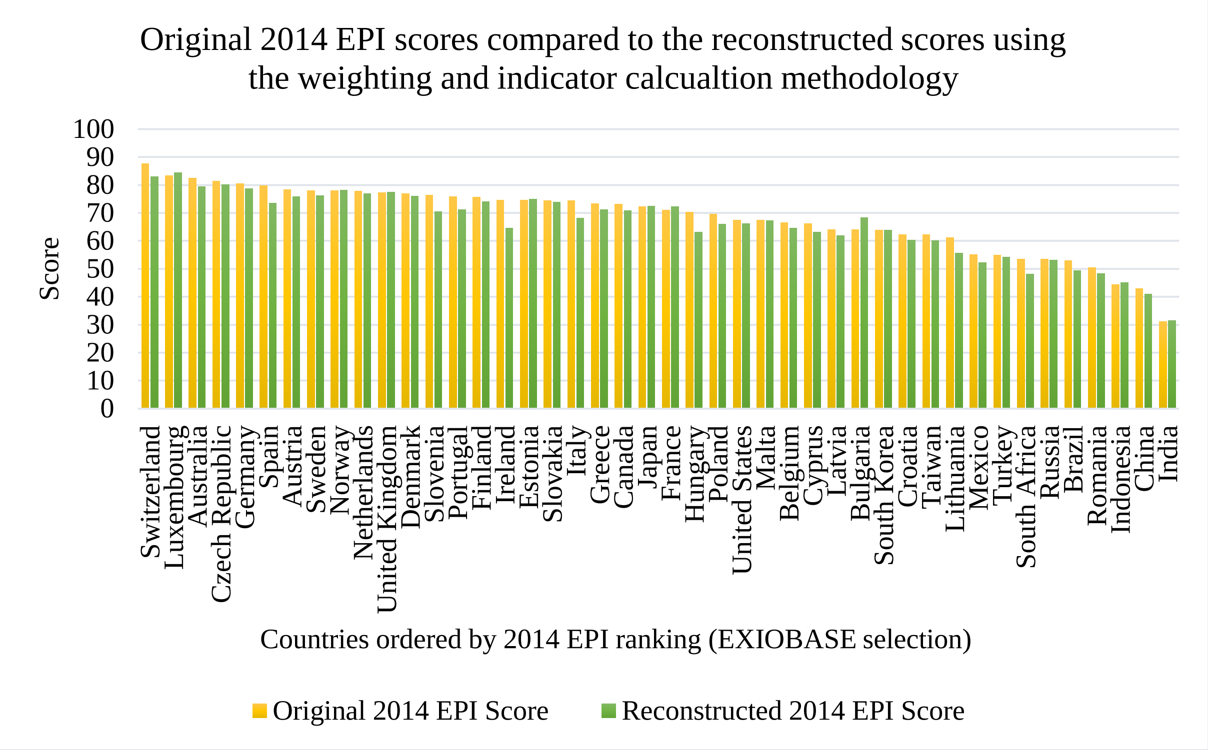


Figure 5: Comparison of the original 2014 EPI index scores and the recalculated index scores presented for the countries included in the 44 EXIOBASE countries.

The results from this section suggest that the EPI is for the most part following their own methodology, and that most of them are reproducible. This provides a good basis for applying and consulting the EPI Metadata and methodology in the following tasks in this thesis. At the same time, it is important to keep in mind that for the less reproducible indicators, the comparison with the EXIOBASE might be affected. Additionally, this comparison is based on the 2014 EPI scores, which is a bit misleading since the raw data values used are mainly from 2012 (although indicators with missing data for 2012 apply the latest available data sources). The issue categories affected by these differences are *Health Impacts* and *Air Quality* (as well as one country for the *Biodiversity and Habitat*). The *Air Quality* is the only one considered for the remaining task, and the differences are sufficiently small to be considered negligible (average deviation of 0,7 score points).

So far, the EPI methodology for score calculation has shown a high degree of reproducibility using the raw data provided. However, reproducing the raw data from on the data sources proved to be more challenging. The indicator raw data is either directly extracted or adapted from their respective data sources. In some cases (e.g. *Change in Forest Cover*) the raw data is easily extracted and calculated from the data source. However for others, the data source is no longer available (e.g. *Water and Sanitation*) or has to be purchased to gain access (e.g. *Trend in CO_2 Emissions per kWh*). Still others have a methodology and data source description that is too insufficient to be able to recreate the raw data from the data source (e.g. *Child Mortality*, *Air Pollution PM2.5 avg. exp.* and *Air Pollution PM2.5 exceedance*). Due to the complexity of the methodology used, and methodology description frequently lacking the necessary detail to recreate the raw data, only the indicators considered for the CBA were fully investigated. The results of the reproducibility is rendered in Table 9 and gives an overview of the reproducibility of each indicator. The column showing data sources to raw data reproducibility is grouped using a combination of numbers and letters. *A* denotes that the indicator data preparation was tested, *B* denotes that the indicator was not tested, *1* denotes reproducibility, and *2* denotes that the indicator data was not exactly reproducible. The detailed justifications for the results in the table for each indicator is found in Appendix F.

Table 9: Overview of the 2014 EPI reproducibility for raw data to score methodology and for data source to raw data. Reproducibility codes for data source to raw data: A=tested, B=not tested, 1= reproducible, 2 = not reproducible.

2014 EPI indicators	Reproducibility		Relevance for CBA
	Data source to raw data	Raw data to score	
Child Mortality	A2	Partially	No
Air Pollution avg. Exp. PM2.5	A2	Yes	Yes
Air Pollution PM2.5 exceedance	A2	Yes	Yes
Household Air Quality	A1	Yes	No
Access to Drinking Water	B (Source no longer available)	Yes	No
Access to Sanitation	B (Source no longer available)	Partially, small deviations occur overall	No
Wastewater Treatment	B	Redundant	No
Critical Habitat Protection	B	Redundant	No
Terrestrial Protected Areas (National Biome Weights)	B	Yes	No
Terrestrial Protected Areas (Global Biome Weights)	B	Yes	No
Marine Protected Areas	B	Partially, some significant deviations	No
Agricultural Subsidies	B	Partially, deviations occur to some countries	Yes
Pesticide Regulation	B	Yes	No
Change In Forest Cover	A1	Partially	Yes
Fish Stocks	B	Yes	Yes
Coastal Shelf Fishing Pressure	B	No	Yes
Trend in Carbon Intensity	A2	Partially, small deviations occur overall	Yes
Change of Trend in Carbon Intensity	A2	Partially, small deviations occur overall	Yes
Trend in CO_2 Emissions per kWh	B (Source only available through purchase)	No	Yes
Access To Electricity	Not used for calculation		

4.2. RESULTS OF THE ADJUSTED WEIGHTING

How much each indicator contributes to the total index score is determined by the individual weighting. The total weighting of the EXIOBASE indicators adds up to 37 % of the total index weighting, as can be seen in Figure 6. The indicators with the highest weightings, and thus the highest influence on the final index score is the *CO_2 Intensity* at 10% and the *PM2.5 Average Exposure* at 8,89 %. The lowest weighting is assigned to the *Agricultural Land Use* at 1,5 %. The EPI methodology assigns weightings based on data set quality and relevance to its measurement, which causes the low weighting in the case of the latter indicator.

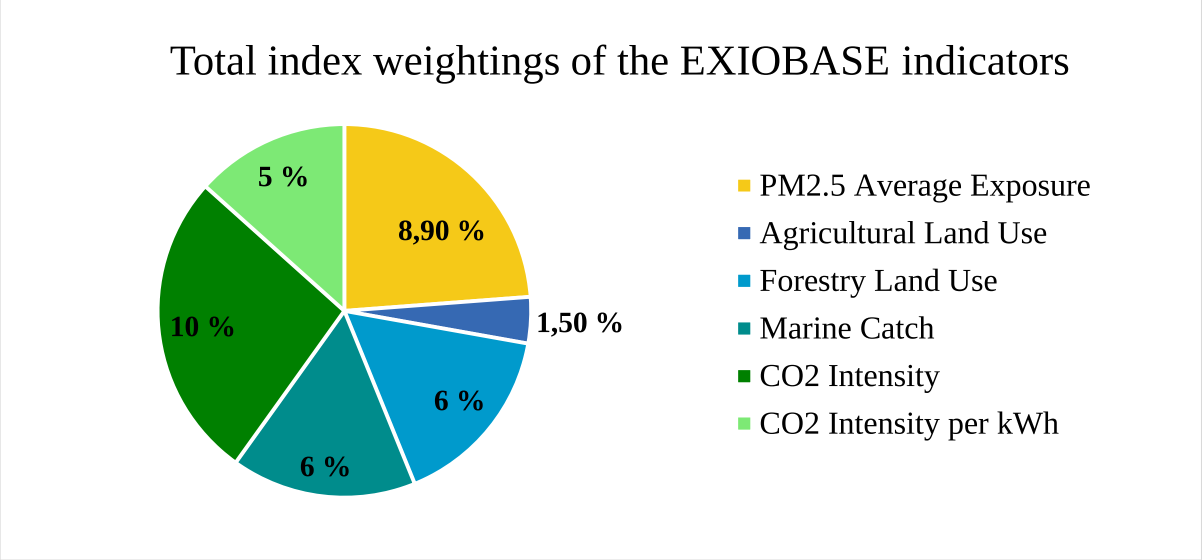


Figure 6: Total index weightings attributed to each EXIOBASE indicator by combining their equivalent objective, issue category and indicator weightings.

The results from this section are used to calculate the influence scores presented next.

4.3. AVERAGE INFLUENCE SCORES

This section looks into how much each indicator influences the total index score. The weightings from the previous section combined with the indicator scores for each calculation scheme (EPI, PBA and CBA) produce the influence scores. The average influence scores are shown in Table 10. Here, both the original EPI indicators and the proposed indicators are displayed. The EPI influence scores in bold signify that several EPI indicators have been combined into the issue category score. For instance, the *Biodiversity and Habitat,* and *Water and Sanitation* issue categories do not change from the EPI to the alternative index, and so the associated indicators are not shown individually.

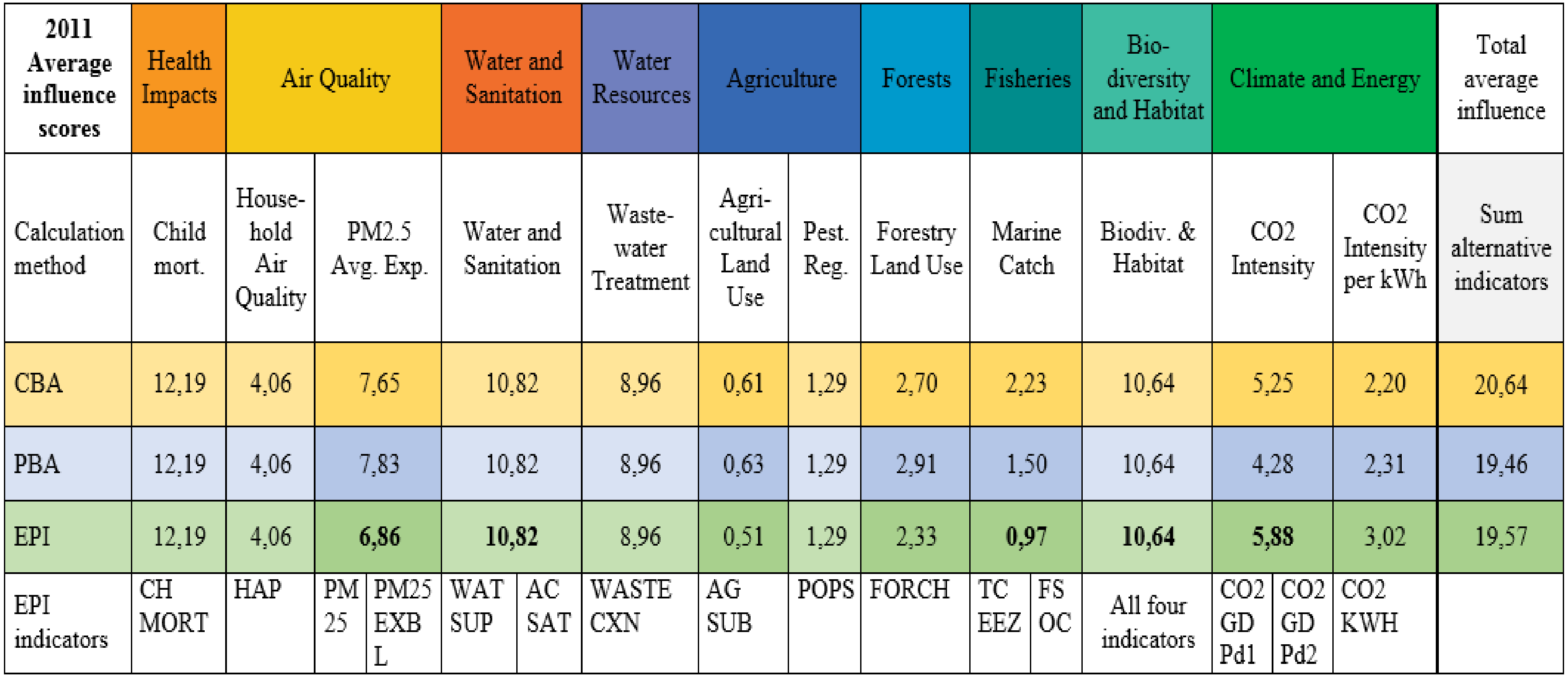
The table shows that the unchanged EPI indicators yield the same average influence for all calculation schemes implying that the influence scores should hold for all the indicators. Furthermore, the total average influence scores combining the average scores of the proposed indicators show a high level of similarity between the calculation schemes. The CBA is around one influence score point higher than the two others, and the PBA and EPI are only separated by 0,11 score points.

A closer look at the individual indicators reveal that the influence scores of the PBA of the CBA are relatively similar for all the proposed indicators and issue categories except for *Fisheries* and *CO_2 Intensity*. The difference found for *Fisheries* is expected because of the materiality filter causing six countries to have scores in the CBA but not in the PBA, thus resulting in a higher influence for the CBA.

The proposed indicators have similar influences to the EPI. This is a sign that the methodology applied to calculate the scores is a good match to the original methodology. The *Air Quality* influence is slightly higher for the EXIOBASE, which is expected due to the abnormal distribution applied which results in scores being more clustered toward the higher end of the score scale. *Agricultural Land Use* is very close to the EPI original (within 0,12 score points), *Forestry Land Use* and *Air Quality* have a bigger deviation, but still less than 1 score point higher than the EPI. *Marine Catch* is also within the 1 score point for the PBA, but as explained before, the CBA is misleading due to the materiality.

That leaves the *CO_2 Intensity*, which is lower than the EPI, and for the PBA by more than 1 score point. This could be due to the differences in calculation methodology, where the EPI uses a trend and the EXIOBASE uses the intensity for 2011. *CO_2 Intensity per kWh* is also lower than the EPI original and also below 1 score point. All in all, the influence chart shows a good correlation between the original EPI index and the proposed consumption-based index with a few larger variations for *Climate and Energy*.

Table 10: Average influence scores for 2011 reflecting the indicator scores multiplied by the individual indicator weighing. The influence thus shows the average contribution to the total index score from each indicator. The indicator names are the abbreviations used in the EPI raw data files. Numbers in bold are the summed original EPI indicators pertaining to one issue category. Fields marked with a darker colouring make up



2011 Average influence scores	Health Impacts	Air Quality		Water and Sanitation	Water Resources	Agriculture		Forests	Fisheries	Bio-diversity and Habitat	Climate and Energy		Total average influence
Calculation method	Child mort.	Household Air Quality	PM2.5 Avg. Exp.	Water and Sanitation	Wastewater Treatment	Agricultural Land Use	Pest. Reg.	Forestry Land Use	Marine Catch	Biodiv. & Habitat	CO2 Intensity	CO2 Intensity per kWh	Sum alternative indicators
CBA	12,19	4,06	7,65	10,82	8,96	0,61	1,29	2,70	2,23	10,64	5,25	2,20	20,64
PBA	12,19	4,06	7,83	10,82	8,96	0,63	1,29	2,91	1,50	10,64	4,28	2,31	19,46
EPI	12,19	4,06	**6,86**	**10,82**	8,96	0,51	1,29	2,33	**0,97**	**10,64**	**5,88**	3,02	19,57
EPI indicators	CHMORT	HAP	PM25 PM25EXBL	WATSUP ACSAT	WASTECXN	AGSUB	POPS	FORCH	TCEEZ FSOC	All four indicators	CO2GDPd1 CO2GDPd2	CO2KWH	

4.4. EVALUATING THE ALTERNATIVE INDEX COMPARED TO THE ORIGINAL EPI FOR 2011

In light of the findings in the previous section, where it becomes clear that the influence of the EXIOBASE indicators only amount to little more than a third of the total index score, this section looks into the methodology differences of adapting the production-based EPI index into a consumption-based index using the EXIOBASE account data for PBA and CBA. First the total EPI index score of 2011 is compared to the PBA index scores which are subsequently compared to the CBA index scores. This is followed by a similar comparison at the indicator level.

The index and the indicator scores are analysed by looking at both scores and ranking differences. The scores are grouped according to their degree of deviation between the EPI and the PBA scores, and between the PBA and the CBA scores, and shown here in Table 11- Table 17 using a colour coding to separate them. The smallest deviation was set to an absolute value of 10 (depicted here in green), followed by absolute values between 10 and 20 score points (yellow), and lastly absolute score points between 20 and 30 (red). Any score deviations above 30 absolute points are shown in white. These intervals were chosen based on the general level of deviation observed across the indicators, and the fact that most deviations were within 30 absolute score points thus making it superfluous to further divide the scores into additional groups.

Rankings are used to give an impression of whether the countries' scores are improving or declining, however it is important to bear in mind that they do not necessarily give a realistic impressions of the magnitudes of the shifts along the ranking scale as the rankings are not directly linked to the score values or to their distribution. For instance, a country may shift 10 ranking places (i.e. almost a fourth of the entire ranking which is seemingly a lot) while at the same time only shifting 10 score points (i.e. a tenth of the total possible score). It is thus the scores that give the correct impression of how the change in methodology has affected the results, although the ranking serves as a supplementary insight into the characteristics of the developments. Ideally, the PBA calculation should result in a similar ranking as the EPI 2014, while the CBA might see smaller or larger shifts depending on the nature of the indicators.

4.4.1. TOTAL INDEX COMPARISON FOR 2011

Figure 7 shows that the EPI total index and the new index calculated using the production-based accounts of the EXIOBASE has a high level of correspondence. All but three countries lie within 10 absolute score points of the original EPI index using PBA, and none have a deviation of more than 20 absolute score points. Shifting to CBA, all countries lie within 10 absolute score points of the PBA scores. This high level of correspondence between the EPI and the PBA would suggest that the alternative index is a good approximation of the original one. The lack of difference between the PBA and the CBA could be caused by smaller differences for this particular year (as will become more apparent in the timeline calculation), or it may be because the total weighting of the substituted indicators only amount to 37 % of the total index score, which means that the original EPI indicators are dominating the final scores.

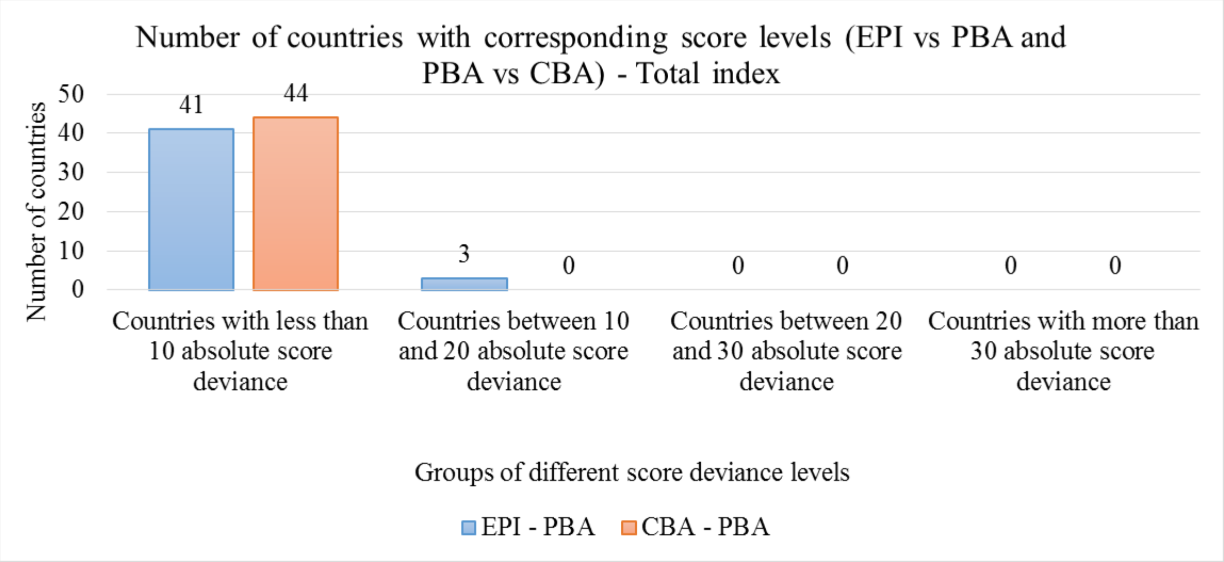


Figure 7: Comparison between the number of countries whose PBA scores match the original EPI and CBA scores. The score deviations are divided into four groups; below 10, between 10 and 20, between 20 and 30, and above 30 absolute scores point.

The average index scores are almost identical for all three calculations, which is again a sign that the alternative index is a good approximation of the original. The average scores are 68,07, 68,15 and 68,61 for the EPI, PBA and CBA respectively. Moreover, the maximum scores are relatively similar at 88,2, 91,8 and 86,4 for the EPI, PBA and CBA respectively. There are no signs of significant tails towards the lower scores except the bottom scores where the EPI is at 31,2, while the two others are at 39,1 (PBA) and 41,9 (CBA). The scores are evenly distributed between all three calculations as shown in Figure 8.

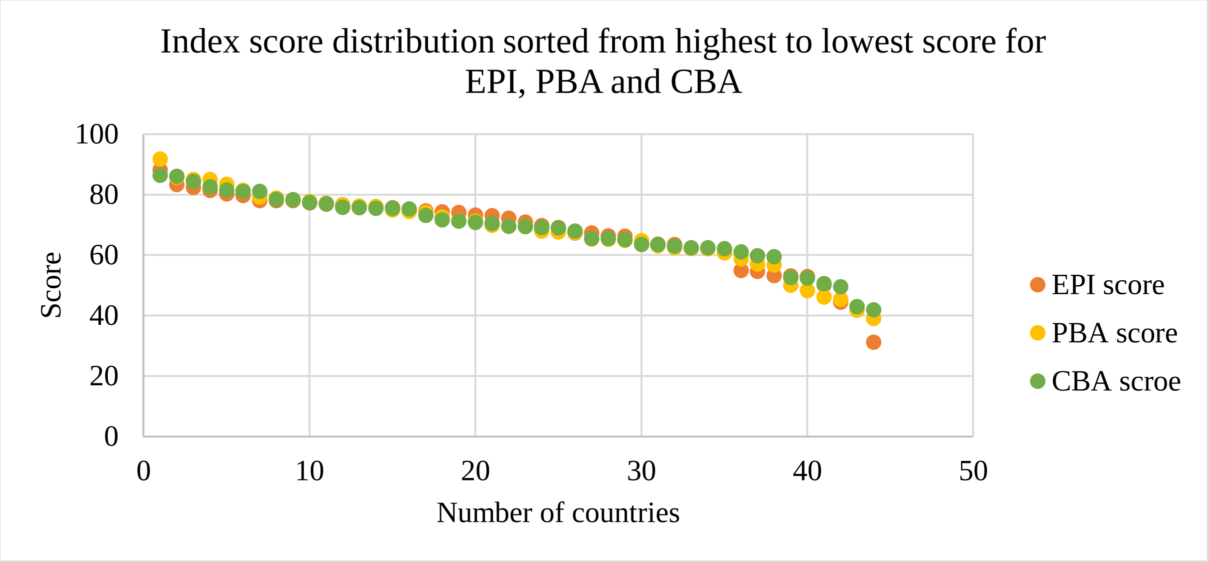


Figure 8: Sorted score distribution for the EPI, PBA and CBA scores by magnitude.

This likeness is reflected in Table 11 where Australia, India and Russia are the only countries with a deviation of more than 10 absolute score points between the EPI and the PBA. The differences between PBA and CBA are equally small and lie between 4,4 and -5,7 score points for the entire data set. The scores are ordered from best to worst performer according to the original EPI, which shows high-income developed countries at the top and lower-income developing countries at the bottom. This is typical for a production-based accounting scheme, as discussed in the Theory chapter.

Table 11: Individual country scores are shown for the EPI, PBA and CBA index in the order of the original EPI. Negative values signifies that the country has gotten a lower score in the PBA than it had in the EPI. The colour coding signifies the level of similarity between the different methodologies. Green = less than absolute value of 10 score point difference, Yellow = between 10 and 20 absolute score point difference, Red = between 20 and 30 absolute score point difference and no colour = exceeding 30 absolute score point difference.

Country	EPI score	PBA score	CBA score	Score difference PBA - EPI	Score difference CBA - PBA
Switzerland	88,17	91,83	86,11	3,66	-5,72
Luxembourg	83,32	85,08	81,58	1,76	-3,50
Australia	82,38	69,50	65,52	-12,88	-3,98
Czech Republic	81,41	79,19	81,08	-2,22	1,90
Germany	80,22	85,76	86,38	5,54	0,62
Spain	79,73	77,23	78,34	-2,50	1,11
Norway	78,04	72,62	73,22	-5,42	0,61
Austria	78,03	81,44	81,10	3,41	-0,35
Sweden	78,03	77,73	76,97	-0,30	-0,76
United Kingdom	77,27	83,47	82,65	6,20	-0,82
Denmark	76,85	76,20	75,71	-0,65	-0,49
Netherlands	76,72	85,09	84,37	8,37	-0,72
Slovenia	75,94	76,11	75,51	0,17	-0,60
Portugal	75,8	74,99	75,25	-0,81	0,26
Finland	75,72	71,24	70,54	-4,48	-0,70
Ireland	74,67	67,98	69,01	-6,69	1,04
Estonia	74,65	65,37	68,03	-9,28	2,66
Slovakia	74,35	74,42	75,78	0,07	1,36
Italy	74,14	78,40	77,43	4,26	-0,97
Greece	73,23	69,94	69,48	-3,29	-0,46
Canada	73,07	63,10	62,98	-9,97	-0,12
Japan	72,2	76,55	75,49	4,35	-1,06
France	70,9	78,90	78,48	8,00	-0,43
Hungary	69,74	67,70	71,68	-2,04	3,98
Poland	69,1	69,52	70,82	0,42	1,30
Malta	67,38	67,52	69,13	0,14	1,61
United States	67,37	64,95	62,49	-2,42	-2,45
Belgium	66,4	74,15	71,25	7,75	-2,90
Cyprus	66,25	64,84	63,58	-1,41	-1,27
Latvia	63,68	62,21	63,48	-1,47	1,26
Bulgaria	63,66	62,44	65,57	-1,22	3,13
South Korea	63,55	71,34	69,58	7,79	-1,76
Taiwan	62,26	65,23	65,08	2,97	-0,15
Croatia	62,15	60,82	62,44	-1,33	1,62
Lithuania	60,93	62,16	62,14	1,23	-0,03
Mexico	54,99	56,72	59,82	1,73	3,10
Turkey	54,65	58,80	61,06	4,15	2,26
Russia	53,29	39,10	41,88	-14,19	2,79
South Africa	53,16	46,16	50,57	-7,00	4,42
Brazil	52,89	50,12	52,61	-2,77	2,50
Romania	50,17	57,05	59,54	6,88	2,49
Indonesia	44,44	48,30	52,45	3,86	4,15
China	43,02	41,76	42,92	-1,26	1,16
India	31,18	45,43	49,56	14,25	4,14

The ranking overview in Figure 9 gives an idea of the general shifts between the methodologies. The rankings reflect the score results where the countries with the largest deviations have the largest ranking shifts. Out of the three countries with the largest score difference, Australia is the only one that sticks out on the ranking as a deviating country which follows the already mentioned discrepancy of the scores and the ranking gaps. However, it is worth noting that the main ranking differences are caused by the EPI to PBA transition. The ranking difference between PBA and CBA relatively small compared to the EPI-PBA and shows little effect of the CBA contribution, with no clear opposing trend to the PBA (e.g. high income countries ranking worse than low income countries).

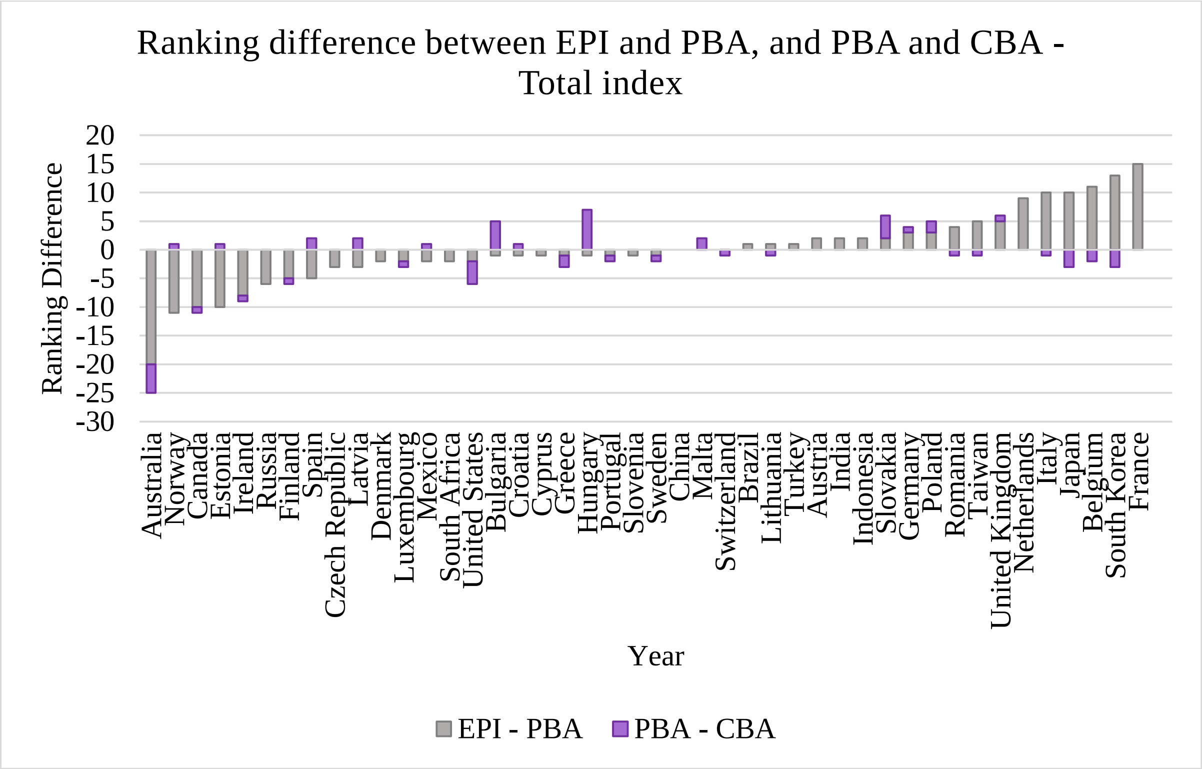


Figure 9: Total Index ranking difference subtracting the PBA ranking from the EPI ranking, and the CBA from the PBA ranking. The positive ranking difference means that the country has improved its ranking in the EXIOBASE indicator compared to the EPI equivalent and vice versa.

4.4.2. ISSUE CATEGORY DIFFERENCES 2011

Although little difference was found between scores for the total index, there may be differences connected to the individual indicators. Differences occurring between the EPI and PBA, and the PBA and CBA for each indicator in 2011 is investigated in the following sections. An overview of the findings is presented below.

The amount of countries with corresponding score values are shown analogous to the previous sections depiction. Differences between the EPI and PBA are shown in Figure 10, and differences between PBA and CBA are shown in Figure 11. Comparing the EPI and the PBA, the *CO_2 Intensity* shows the highest degree of correspondence with 34 countries within the absolute 20 score point deviance range, which is expected since it is the indicator with the most similar measurement to the EPI. *Marine Catch* follows close behind at 30 common countries within this same range. *CO_2 Intensity per kWh* is has the worst fit, with 17 countries outside the 30 point absolute score range and only eight countries with an absolute score point deviance below 10. The *Forestry Land Use* is slightly better with 10 countries within the smallest deviation, and 18 countries above the 30 point threshold.

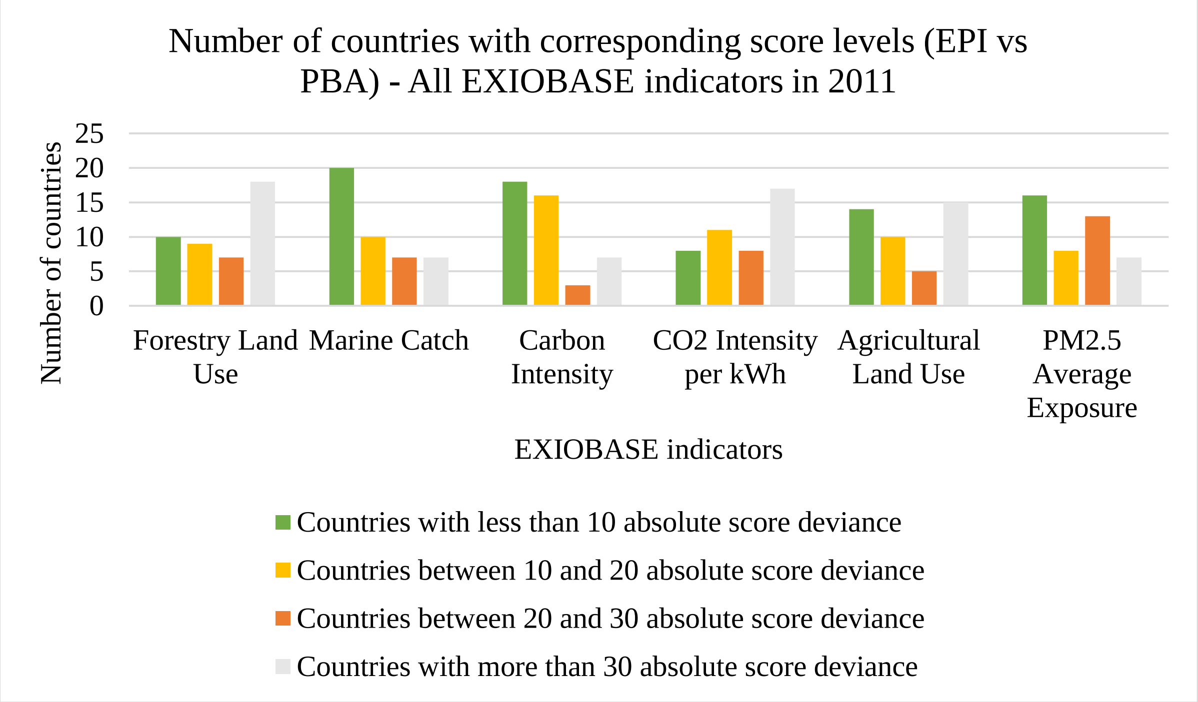


Figure 10: Comparison between the number of countries whose PBA scores match the original EPI scores in 2011. The scores deviations are divided into four groups; below 10, between 10 and 20, between 20 and 30, and above 30 absolute scores point.

However, it is the total index weighting that determines how large an effect these differences will have on the final index score. Comparing these results in light of the total index weighting attributed to each indicator (Figure 6) gives an indication of how large the influence of each indicators score is going to be on the final index score. For instance, the *Agricultural Land Use* indicator has 15 countries exceeding the 30 point threshold making it a relatively poor fit, but since it only represents 1,5 % of the total index score the consequences are small. The CO_2 Intensity on the other hand has the best fit, and the highest index weighting. The results from this can thus be expected to be in line with the EPI, and have a noticeable influence on the final index score. Since the PBA is adapted to fit the original EPI as well as possible, any differences found between these two are signs of the methodological and measurement differences. That being said, these deviations should not affect the analysis of the deviations between PBA and CBA since they are both affected by the same limitations and thus be canceled out.

Between the PBA and the CBA indicator scores for 2011 the tendency is similar to the trends seen between the EPI and PBA for all the indicators except for *Agricultural Land Use* (see Figure 11). These have a high score correspondence between the PBA and the CBA, meaning that there is no evidence of a large shift between accounting schemes. The remaining indicator shows a larger spread in its score distribution. This result implies that a shift in country score and ranking is present, but it does not give information on which countries have shifted.

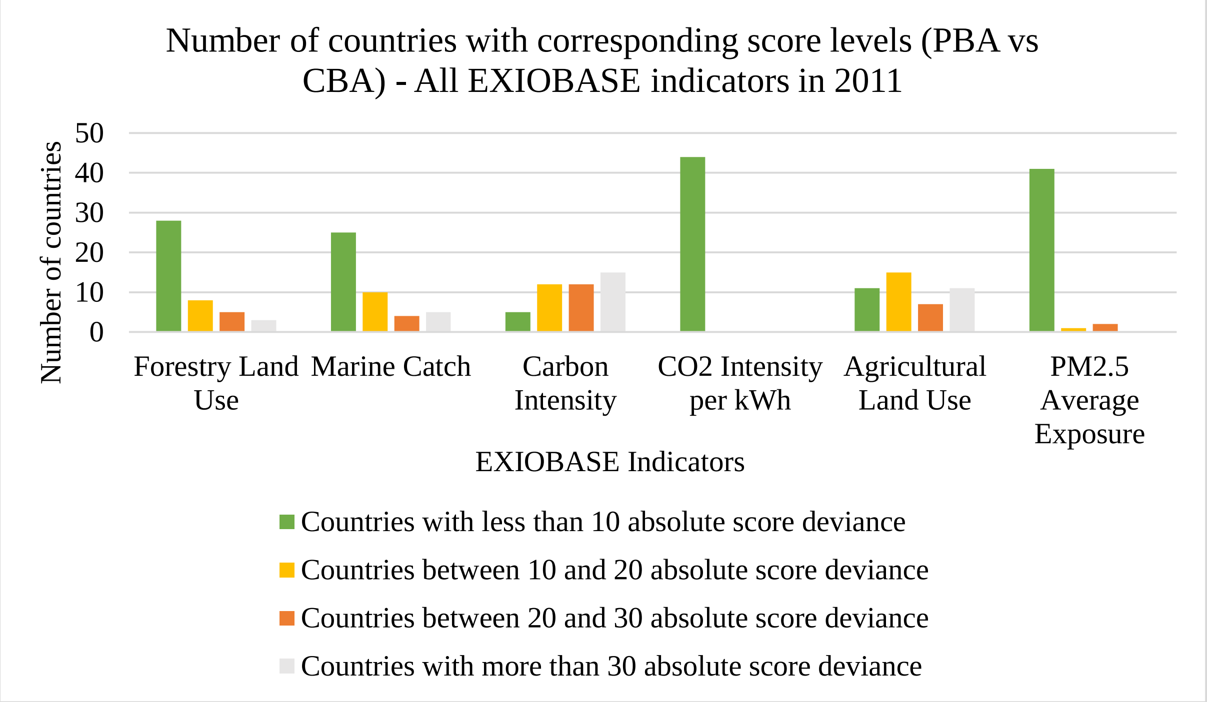


Figure 11: Comparison between the number of countries whose CBA scores match the PBA scores in 2011. The scores deviations are divided into four groups; below 10, between 10 and 20, between 20 and 30, and above 30 absolute scores point.

The following subsections investigate each indicator with regards to the similarities and deviations between the EPI and the PBA, and the PBA and the CBA scores in a similar fashion as above.

4.4.2.1. PM2.5 Average Exposure

The scores of the two PM2.5 indicators of the EPI are combined using the indicator weighting in order to compare them to the equivalent EXIOBASE indicator which is multiplied by the same weighting ensuring their correlation.

Table 12 shows relatively good correspondence between the EPI and the PBA scores. 16 of the countries lie within 10 absolute score points for this indicator. This is the third highest correspondence within the green score deviance grouping even though it makes up less than half the countries. Furthermore, eight countries are within the yellow range, 13 are in the red range, while seven lie outside the 30 absolute score point threshold. The latter is the lowest number of countries in this score deviance group across all indicators, and shares the count with *CO_2 Intensity* and *Marine Catch.* Among these seven countries Australia, Brazil, Canada, Russia and India have the highest deviation (more than 40 absolute score points).The first four are all countries with large land areas relative to their population. The EPI uses a population grid, which corrects for area differences in population densities, while the EXIOBASE indicators are calculated using an average for the entire country, which could explain why their scores drop. For India, the score increases. India has one of the higher population densities among the 44 countries, and see a corresponding score increase, which has the opposite effect compared to the countries of low population densities.

In general, all countries increase their scores going from EPI to PBA, except for the US and the four large population density countries already mentioned. The score increase is maintained for the CBA with minor changes, except for Canada in the yellow range, and Australia and the US in the red range. These are high income countries that already saw a large changes going from EPI to PBA, and are getting increasingly lower scores going from PBA to CBA. This suggests that the differences found in this indicator are more due to the methodological differences than the accounting scheme differences. The lower performers of the EPI are moving towards the top performers for the PBA, but this is likely due to the score distribution. Further investigation into the timeline deviations may shed light on whether this is a specific result for 2011 or if it is a general trend.

The average values of the PBA and CBA are slightly higher (58,7 and 57,4) than the EPI (51,5). This is due to the clustering of the EXIOBASE dataset caused by the abnormal distribution used for this indicator. The tail values observed for the EXIOBASE dataset are thus higher than those of the EPI whose scores are more evenly distributed. This deviation is however significantly better than the alternative if using the logarithmic transform which results in an average of just 24,8 for PBA.

Table 12: Individual country scores for the EPI, PBA and CBA PM2.5 Average Exposure indicator multiplied by the weighting of 66% and ordered by EPI score performance. Negative values signifies that the country has gotten a lower score in the PBA than it had in the EPI. The colour coding signifies the level of similarity between the different methodologies. Green = less than absolute value of 10 score point difference, Yellow = between 10 and 20 absolute score point difference, Red = between 20 and 30 absolute score point difference and no colour = exceeding 30 absolute score point difference.

Country	EPI score	PBA score	CBA score	Score difference PBA - EPI	Score difference CBA - PBA
Australia	66,67	25,73	0,88	-40,93	-24,86
Finland	66,67	64,99	64,39	-1,68	-0,59
Ireland	66,67	66,33	66,28	-0,34	-0,05
Malta	66,67	66,67	66,67	0,00	0,00
Norway	66,67	60,06	60,04	-6,61	-0,02
Estonia	66,55	66,08	66,17	-0,47	0,09
Brazil	66,43	23,60	25,38	-42,83	1,79
Portugal	66,31	66,41	66,33	0,10	-0,08
Canada	65,71	24,23	12,66	-41,48	-11,56
Spain	65,71	65,53	64,90	-0,18	-0,63
South Africa	65,47	58,47	59,61	-7,00	1,14
Sweden	64,99	65,38	64,55	0,39	-0,83
Latvia	64,63	66,23	66,20	1,60	-0,03
United States	63,91	38,13	16,61	-25,78	-21,53
United Kingdom	63,67	66,27	65,85	2,60	-0,43
Indonesia	61,63	58,72	58,44	-2,91	-0,28
Denmark	60,68	66,20	66,18	5,52	-0,02
Russia	60,05	0,00	0,00	-60,05	0,00
Mexico	58,76	58,15	60,49	-0,61	2,34
France	56,66	64,85	63,98	8,19	-0,87
Cyprus	54,12	66,58	66,59	12,46	0,00
Greece	53,84	64,84	65,19	11,00	0,34
Japan	52,41	65,55	65,29	13,14	-0,27
Lithuania	51,78	66,41	66,36	14,63	-0,05
Turkey	50,50	62,96	62,72	12,46	-0,24
Luxembourg	50,40	66,65	66,64	16,25	-0,01
Switzerland	48,64	66,50	66,40	17,86	-0,09
Italy	47,56	65,87	65,30	18,31	-0,56
Croatia	45,59	66,50	66,47	20,91	-0,03
Germany	44,96	65,47	65,15	20,50	-0,32
Taiwan	44,37	66,56	66,54	22,19	-0,02
Bulgaria	43,91	66,30	66,22	22,39	-0,08
Netherlands	43,09	66,60	66,52	23,51	-0,08
Austria	42,62	66,45	66,28	23,83	-0,17
Slovenia	42,49	66,58	66,56	24,09	-0,02
Czech Republic	40,23	66,39	66,34	26,16	-0,05
Slovakia	39,38	66,48	66,47	27,10	-0,01
Romania	38,90	65,78	65,70	26,88	-0,08
Belgium	36,98	66,59	66,49	29,61	-0,09
Poland	36,14	65,28	65,07	29,14	-0,22
Hungary	34,72	66,42	66,37	31,70	-0,05
South Korea	28,05	66,35	66,18	38,30	-0,17
India	9,43	57,17	57,59	47,74	0,42
China	0,34	0	0	-0,34	0,00

Figure 12 shows the ranking differences, where a similar results is seen here as for the total index, namely that the main differences occur between the EPI and the PBA, while relatively small changes are seen when shifting to CBA. However, among the countries that drop in ranking placement from the CBA are industrialized countries like Norway and the UN, while China stays the same.

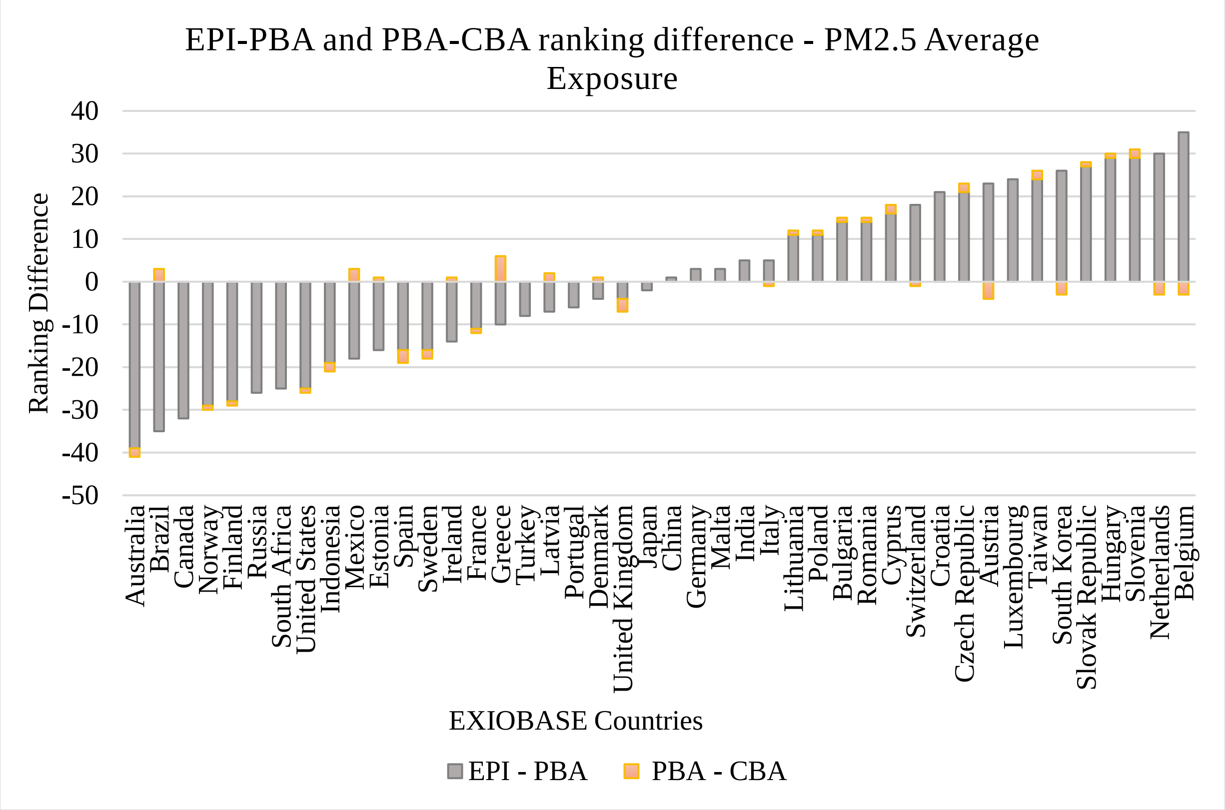


Figure 12: PM 2.5 Average Exposure ranking difference subtracting the PBA ranking from the EPI ranking, and the CBA from the PBA. The positive ranking difference means that the country has improved its ranking in the EXIOBASE indicator compared to the EPI equivalent and vice versa.

4.4.2.2. Agricultural Land Use

Table 13 shows that there are more countries beyond the 30 absolute score deviation threshold than there are countries within the green deviance level (15 and 14 countries respectively). In other words, a third of the 44 countries each. The last third consists of 10 countries within the yellow deviation group and 5 within the red one. The difference between the EPI and the PBA were expected to be significant for this indicator since the proxy used to calculate the EPI is based on GNI and subsidies received, and the PBA was based on land use per capita. In other words, this indicator is not going to have an optimal comparison. In addition the score distribution of the EPI has its highest score at 71,2, while the PBA has a 100 in accordance with the methodology for the alternative indicators, which contributes added deviation between the two methodologies. However, since the agriculture is given a low weighting in the EPI, these differences should not constitute a large contribution to the overall score.

Comparing the PBA and CBA shows that 11 countries are within the green deviation group, 15 are in the yellow, seven in the red and 11 are beyond the 30 average score point deviance threshold. The greatest positive shift is seen for India at 36,7 points difference, while the largest negative shifts are seen for Belgium, Luxemburg, Malta, Netherlands, Taiwan, South Korea and Japan (deviations of more than 40 absolute score points). This is a result in line with the expectations from shifting to a CBA scheme where high income countries experience a drop in score value, while developing countries are increasing their performance.

As mentioned, there score distribution of the EPI and the EXIOBASE indicators are causing larger score deviations due to the calculation methodology differences. The alternative index is scored using a target of best and worst performer, which results in the alternative index having a tail of higher scores at the top e nog the score range. The tails at the bottom are quite similar for the EPI and the PBA, while the CBA has no values below 20 except for the ones set to zero through the target settings of the alternative methodology. This causes the average of the EPI (34,2) to be lower than the PBA (41,7) and the CBA (41).

Table 13: Individual country scores are shown for the EPI, PBA and CBA Agricultural Land Use indicator in the order of the EPI. Negative values signifies that the country has gotten a lower score in the PBA than it had in the EPI. The colour coding signifies the level of similarity between the different methodologies. Green = less than absolute value of 10 score point difference, Yellow = between 10 and 20 absolute score point difference, Red= between 20 and 30 absolute score point difference and no colour = exceeding 30 absolute score point difference.

Country	EPI score	PBA score	CBA score	Score difference PBA - EPI	Score difference CBA - PBA
Bulgaria	71,24	24,45	60,44	-46,79	35,99
South Africa	70,41	3,04	21,80	-67,37	18,76
Brazil	61,01	9,12	30,34	-51,89	21,22
Australia	56,91	0,00	0,00	-56,91	0,00
Romania	52,27	24,78	48,33	-27,49	23,56
United States	43,05	9,10	22,31	-33,95	13,21
Denmark	40,11	33,29	33,94	-6,82	0,65
Slovakia	39,71	41,33	54,05	1,62	12,72
France	39,09	35,86	36,63	-3,23	0,77
Austria	38,98	43,97	40,41	4,99	-3,55
Hungary	38,68	30,69	62,12	-7,99	31,43
Belgium	38,67	67,76	27,49	29,09	-40,27
Luxembourg	38,67	49,49	0,00	10,82	-49,49
Germany	38,62	55,01	42,58	16,39	-12,43
Spain	38,38	32,71	37,36	-5,67	4,65
Sweden	38,35	44,90	40,22	6,55	-4,69
Estonia	38,24	23,33	37,53	-14,91	14,20
Czech Republic	38,14	38,63	53,26	0,49	14,63
Greece	38,01	36,05	43,38	-1,96	7,33
Finland	37,98	36,59	37,70	-1,39	1,11
Italy	37,75	54,67	41,15	16,92	-13,52
Lithuania	37,22	17,08	36,31	-20,14	19,24
Latvia	37,15	18,91	41,14	-18,24	22,23
Ireland	36,77	17,67	30,62	-19,10	12,95
Portugal	36,6	46,56	43,18	9,96	-3,38
United Kingdom	36,07	52,57	44,18	16,50	-8,39
Malta	35,31	100,00	54,50	64,69	-45,50
Slovenia	34,86	53,76	45,53	18,90	-8,22
Netherlands	34,73	69,51	26,81	34,78	-42,71
Cyprus	34,68	70,61	52,17	35,93	-18,43
Poland	33,95	38,81	56,94	4,86	18,12
Mexico	30,41	23,41	43,28	-7,00	19,87
Canada	29,04	0,00	21,46	-29,04	21,46
Croatia	25,98	25,60	39,01	-0,38	13,41
India	24,79	63,35	100,00	38,56	36,65
Russia	21,87	6,93	25,75	-14,94	18,82
Indonesia	19,7	57,00	81,96	37,30	24,96
Taiwan	17,93	90,93	37,97	73,00	-52,96
Turkey	17,34	31,55	42,49	14,21	10,94
China	15,71	45,02	68,69	29,31	23,68
Switzerland	6,48	57,99	29,41	51,51	-28,58
South Korea	1,97	98,53	40,82	96,56	-57,70
Norway	1,19	57,65	23,94	56,46	-33,70
Japan	0,96	96,34	46,40	95,38	-49,94

Figure 13 shows how the country rankings have shifted between the EPI and the PBA. Again, the largest shift are seen between EPI and PBA, but the differences between PBA and CBA are more noticeable here compared to the *PM2.5 Average Exposure* and the total index. The major shifts are seen for high income countries like Luxembourg, the Netherlands, Norway and Switzerland, while Mexico, Hungary and Romania are increasing their ranking.

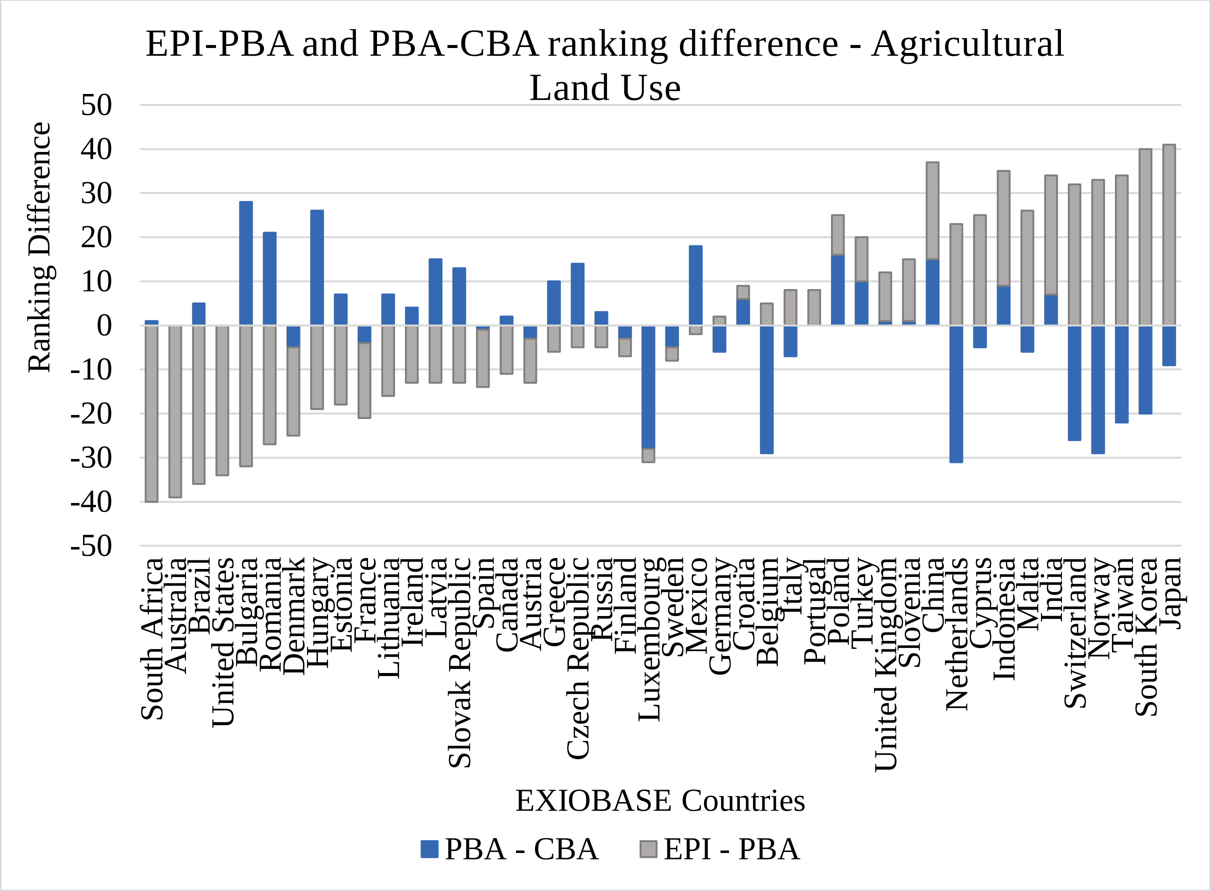


Figure 13: Agricultural Land Use ranking difference subtracting the PBA ranking from the EPI ranking, and the CBA from the PBA. The positive ranking difference means that the country has improved its ranking in the EXIOBASE indicator compared to the EPI equivalent and vice versa.

4.4.2.3. Forestry Land Use

Table 14 shows that when comparing the EPI to the PBA scores, 18 countries (almost half) lie outside the 30 absolute score deviation threshold which is the highest amount across all indicators. The remaining countries are divided between the three groups of score deviations, where 10 are in the green group, nine are in the yellow and seven are in the red group. The differences seen between the EPI and the PBA are likely due to the trend used by the EPI, and the measure of net change, not the absolute measure. Countries who have significantly lowered their forest land use will therefore score better in the EPI, while the PBA is only concerned with the land use per capita for one year. The largest difference (more than 50 absolute score deviance) are seen for Australia (negative deviation), and Belgium, UK, Denmark, Portugal, India and the Netherlands (positive deviation).

The score deviations between PBA and CBA are smaller than between the EPI and the PBA, where 27 are within the green group, eight are yellow, five red and only four beyond these groupings (Taiwan UK, Netherlands and Malta). Malta is a special case since it is not given a score in the PBA due to the materiality, making this score difference inaccurate. Compared to the other land use indicator (*Agricultural Land Use*), there is less deviance between the PBA and CBA for *Forestry Land Use*, however Netherlands, Malta and Taiwan are common for both. One surprising result is that India is scoring 100 for bot PBA and CBA, and Canada is scoring 0 for both which might not be realistic, but is caused by the target methodology of the alternative index. Still, it signifies a lack of difference between the two accounting schemes for these two countries in 2011.

The score averages of the three calculations are fairly similar; EPI at 38,9, PBA at 48,6 and CBA at 45,7. However, the PBA scores have a tail at the top end which causes an elevated average compared to the others. The EPI has only six countries scored between 60 and 100, while the PBA has 16 countries within the same range.

Table 14: Individual country scores are shown for the EPI, PBA and CBA Forestry Land Use indicator in the order of the EPI. Negative values signifies that the country has gotten a lower score in the PBA than it had in the EPI. The colour coding signifies the level of similarity between the different methodologies. Green = less than absolute value of 10 score point difference, Yellow = between 10 and 20 absolute score point difference, Red= between 20 and 30 absolute score point difference and no colour = exceeding 30 absolute score point difference.

Country	EPI score	PBA score	CBA score	Score difference PBA - EPI	Score difference CBA - PBA
Australia	100	17,51	25,64	-82,49	8,12
Hungary	100	56,61	61,85	-43,39	5,24
Ireland	100	69,69	56,17	-30,31	-13,52
South Africa	100	69,77	76,72	-30,23	6,94
Bulgaria	84,12	35,02	42,81	-49,10	7,80
Croatia	63,12	37,53	38,82	-25,59	1,29
Poland	58,94	52,46	59,84	-6,48	7,39
Italy	55,41	65,31	54,31	9,90	-11,01
Japan	55,41	60,11	46,67	4,70	-13,44
Turkey	52,35	65,87	65,59	13,52	-0,28
Switzerland	49,65	59,30	47,03	9,65	-12,27
Taiwan	49,65	77,01	38,59	27,36	-38,43
Czech Republic	45,05	51,69	58,04	6,64	6,34
Romania	45,05	46,47	52,28	1,42	5,81
Slovenia	45,05	33,52	37,64	-11,53	4,13
Spain	45,05	55,97	57,95	10,92	1,99
United Kingdom	43,06	94,82	60,73	51,76	-34,09
France	37,94	53,16	46,58	15,22	-6,58
Cyprus	35,07	80,03	73,90	44,96	-6,14
India	35,07	100,00	100,00	64,93	0,00
Russia	35,07	0,00	9,08	-35,07	9,08
Luxembourg	33,76	58,61	38,70	24,85	-19,91
Netherlands	33,76	96,67	54,26	62,91	-42,42
South Korea	33,76	73,63	49,30	39,87	-24,33
Norway	32,52	11,83	9,24	-20,69	-2,58
Germany	31,35	63,96	51,93	32,61	-12,03
China	25,34	72,60	63,59	47,26	-9,01
Belgium	23,64	76,28	48,70	52,64	-27,58
Lithuania	23,64	28,34	42,86	4,70	14,51
Greece	22,83	48,94	48,22	26,11	-0,73
Slovakia	21,31	43,69	57,03	22,38	13,34
Austria	19,87	38,65	37,25	18,78	-1,40
Mexico	19,87	48,40	51,11	28,53	2,72
Denmark	18,52	72,43	45,86	53,91	-26,57
Canada	16,64	0,00	0,00	-16,64	0,00
Sweden	14,35	3,84	5,81	-10,51	1,97
United States	14,35	29,82	28,20	15,47	-1,62
Finland	11,77	0,17	0,00	-11,60	-0,17
Brazil	10,81	17,10	18,78	6,29	1,68
Estonia	9,02	10,61	38,54	1,59	27,93
Indonesia	7,75	38,88	45,21	31,13	6,33
Portugal	7,75	60,98	55,42	53,23	-5,57
Latvia	3,3	11,57	32,31	8,27	20,74
Malta	NA	NA	79,28	NA	79,28

Figure 14 shows the ranking differences between the EPI and the PBA, and the between the PBA and the CBA. In accordance with the findings of the score deviations, the major ranking differences are seen between the EPI and the PBA. Switching from PBA to CBA results in Malta sticking out because of the materiality filter applied as well as Taiwan which experiences a large drop reflected in the score deviation. Apart from these two countries, the ranking differences remain relatively small and evenly distributed across all countries.

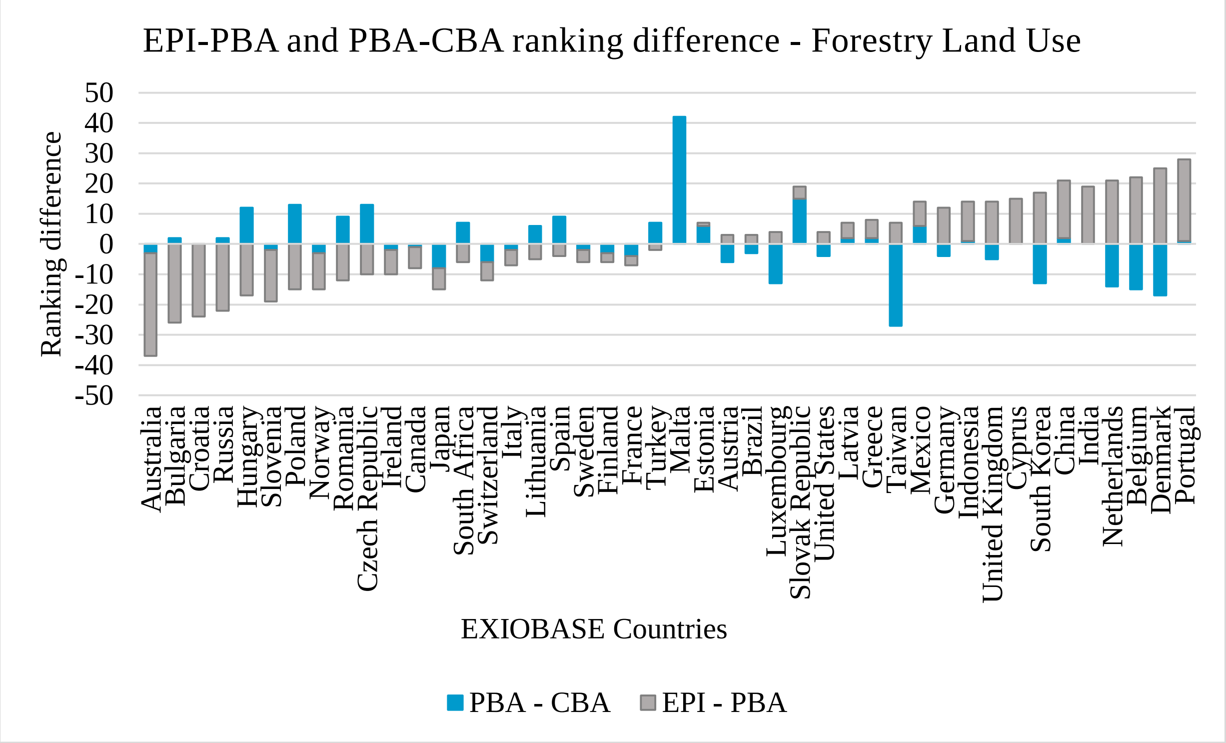


Figure 14: Ranking difference subtracting the PBA ranking from the EPI ranking, and the CBA from the PBA. The positive ranking difference means that the country has improved its ranking in the EXIOBASE indicator compared to the EPI equivalent and vice versa.

4.4.2.4. Marine Catch

The alternative indicator combines the two indictors of the Fisheries issue category which is thus used for the comparison. The materiality filters applied to the EPI indicator are only partially transferred to the EXIOBASE indicator, and is expected to cause score differences. Moreover, the indicator methodologies differ in that EPI measures overfishing, while the alternative indicator measures of catch per capita.

Comparing the EPI and the PBA scores listed in Table 15 shows that 20 of the countries are within the green deviation group, 10 are found in the yellow, and seven are found in each of the reaming groups (red and beyond the 30 absolute score point threshold). The materiality filter causes Belgium, Bulgaria, France, Malta, Romania, Slovenia ant the UK to have large deviation between the EPI and the PBA. In other words, the PBA is an acceptable approximation of the EPI despite the methodological differences.

Comparing PBA to CBA shows that there are unrealistically elevated difference for the countries that were not scored in the PBA due to the *Landlock* materiality filter. Apart from this, all deviations are within the 30 absolute score deviation, and the largest positive differences are observed for Bulgaria, India, and South Africa, while Belgium has the largest negative shift. Norway is the worst performer of both PBA and CBA because of the large catch per capita being set to zero by the target methodology. This is a good example of the drawback of applying a general target methodology.

The tail differences are the most significant for this indicator compared to the other alternative indicators. The EPI's combined issue category top score is 32,9 while the EPI is at 100. This results in an average alternative indicator score that is around twice as large as the EPI average (16,1). The PBA average is 33,0 elevated by the difference in materiality filter application. The CBA has an average of 37,1 which is further elevated because of the landlocked countries now receiving a score as opposed to the production-based scores.

Table 15: Individual country scores are shown for the EPI, PBA and CBA Marine Catch indicator in the order of the EPI. Negative values signifies that the country has gotten a lower score in the PBA than it had in the EPI. The colour coding signifies the level of similarity between the different methodologies. Green = less than absolute value of 10 score point difference, Yellow = between 10 and 20 absolute score point difference, Red= between 20 and 30 absolute score point difference and no colour = exceeding 30 absolute score point difference.

Country	EPI score	PBA score	CBA score	Score difference PBA - EPI	Score difference CBA - PBA
Austria	NA	NA	59,26	NA	59,26
Czech Republic	NA	NA	68,21	NA	68,21
Hungary	NA	NA	91,78	NA	91,78
Luxembourg	NA	NA	18,05	NA	18,05
Slovakia	NA	NA	83,79	NA	83,79
Slovenia	NA	69,70	63,05	69,70	-6,64
Switzerland	NA	NA	41,48	NA	41,48
Finland	32,89	24,40	17,27	-8,49	-7,13
Cyprus	32,32	57,78	51,31	25,46	-6,48
Portugal	30,07	25,09	13,11	-4,98	-11,98
Estonia	27,66	13,82	7,01	-13,84	-6,81
Taiwan	27,04	18,15	5,51	-8,89	-12,64
Poland	26,52	41,25	45,13	14,73	3,87
Greece	25,86	39,58	37,17	13,72	-2,41
Indonesia	25,8	24,63	30,44	-1,17	5,81
Japan	25,34	21,61	8,33	-3,73	-13,28
Mexico	25,34	31,21	44,64	5,87	13,43
Sweden	25,3	25,85	17,60	0,55	-8,25
Italy	24,93	44,78	34,02	19,85	-10,77
Brazil	24,68	47,07	47,14	22,39	0,07
Spain	23,24	24,53	11,74	1,29	-12,79
India	22,64	47,87	75,92	25,23	28,05
South Korea	22,24	19,56	12,05	-2,68	-7,51
Turkey	21,9	37,54	55,57	15,64	18,03
Canada	21,54	24,21	29,57	2,67	5,36
Norway	20,88	0,00	0,00	-20,88	0,00
Australia	19,37	36,70	34,43	17,33	-2,27
Croatia	19,3	27,33	32,69	8,03	5,36
Ireland	16,49	16,06	19,51	-0,43	3,45
China	14,68	32,80	42,57	18,12	9,77
Germany	13,4	46,84	47,24	33,44	0,41
Russia	12,73	22,76	23,37	10,03	0,61
Denmark	8,66	0,82	0,00	-7,84	-0,82
United States	3,34	28,51	26,70	25,17	-1,81
South Africa	2,52	32,41	53,33	29,89	20,92
Belgium	0	50,70	28,92	50,70	-21,78
Bulgaria	0	57,90	87,25	57,90	29,35
France	0	36,70	26,63	36,70	-10,07
Latvia	0	10,68	7,65	10,68	-3,03
Lithuania	0	16,17	7,72	16,17	-8,45
Malta	0	41,77	48,59	41,77	6,82
Netherlands	0	24,21	36,35	24,21	12,14
Romania	0	100,00	100,00	100,00	0,00
United Kingdom	0	33,92	41,99	33,92	8,07

The ranking differences displayed in Figure 15 clearly show the impact of the materiality filter application difference between the PBA and the CBA. The remaining rankings mostly fall in line with the direction of the EPI – PBA ranking difference, except for the group of countries that increase their ranking from EPI to PBA. Here, Belgium, Italy and France stand out showing an opposite trend.

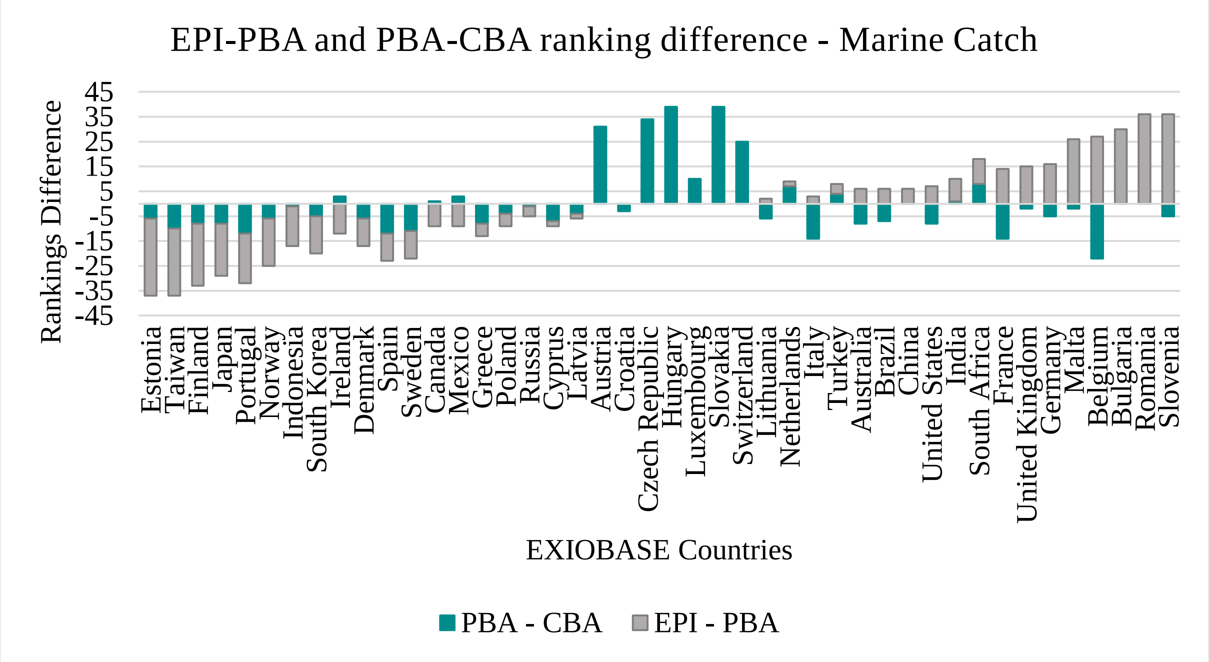


Figure 15: Marine Catch ranking difference subtracting the PBA ranking from the EPI ranking, and the CBA from the PBA. The positive ranking difference means that the country has improved its ranking in the EXIOBASE indicator compared to the EPI equivalent and vice versa.

4.4.2.5. CO_2 Intensity

As for the two EPI indicators of the *Air Quality* issue category, two of the indicators (*Trend in Carbon Intensity* and *Change of Trend in Carbon Intensity*) from the *Climate and Energy* issue category are combined into one EXIOBASE equivalent.

This is the indicator with the second highest number of countries within the 10 absolute score point deviation group at 18. It has the highest number of countries within the yellow group at 16 which leaves seven in the red group and only three outside the 30 absolute score point threshold. This is the lowest amount of countries in the latter group across all indicators. In other words, the EPI and the PBA match very well, as can be seen in Table 16. The deviations are largest for China, Cyprus, Czech Republic, Greece, Estonia, Russia and South Africa. This is likely caused by the methodology difference where the EPI uses a trend to rank the countries based on their carbon intensity level over time. Developing countries are therefore likely to score better in the EPI than the PBA since they have the largest potential of decreasing their CO_2 intensity, as opposed to industrialized countries that already have lower energy intensities. China and Russia are good representatives of this effect.

Switching from PBA to CBA results in a large amount of corresponding score with relatively small deviances. 31 countries are found within the green score deviation group, and 11 within the yellow, and the remaining two are within the red group. Indonesia and Taiwan have the largest score deviation, and both improve their score. This is a general trend for all countries, where the majority improve their scores with varying degree. Australia, Switzerland, and Slovakia are the three countries with the largest negative score deviance, but this deviance is still within the green score deviance group.

The average score of the EPI for the combined EPI indicators is 39,2, while the PBA average score is at 28,6 and the CBA is at 35. The deviation in EPI and PBA average is caused by the tail present in the lower end of the PBA scores where 36 countries score below 40. The EPIs lowest score is 17,9, while the PBA's and CBA's lowest score is 0. These differences are ultimately a result of the difference in target methodology. The top scores are much closer, with the PBA and CBA at 60, and the EPI at 54,7.

Table 16: EPI indicator scores for the Trend and Change of Trend in Carbon Intensity indicators combined. Individual country scores are shown for the EPI, PBA and CBA indicator in the order of the EPI. Negative values signifies that the country has gotten a lower score in the PBA than it had in the EPI. The colour coding signifies the level of similarity between the different methodologies. Green = less than absolute value of 10 score point difference, Yellow = between 10 and 20 absolute score point difference, Red= between 20 and 30 absolute score point difference and no colour = exceeding 30 absolute score point difference.

Country	EPI score	PBA score	CBA score	Score difference PBA – EPI	Score difference CBA – PBA
Slovakia	54,75	32,31	26,78	-22,44	-5,53
Spain	51,85	40,41	52,85	-11,43	12,44
Sweden	51,70	58,51	60,00	6,81	1,49
Portugal	50,68	40,98	51,26	-9,70	10,28
China	47,88	0,00	5,09	-47,88	5,09
Czech Republic	47,67	17,28	25,49	-30,39	8,21
Ireland	46,73	34,95	44,87	-11,78	9,92
Romania	45,63	33,88	46,63	-11,75	12,76
Denmark	45,45	29,86	37,49	-15,59	7,63
Switzerland	45,26	60,00	50,09	14,74	-9,91
Russia	45,09	9,17	22,36	-35,92	13,19
Poland	44,20	18,38	21,23	-25,82	2,85
Norway	43,87	39,55	49,52	-4,32	9,97
Luxembourg	43,47	38,73	53,06	-4,74	14,33
Germany	43,34	30,92	41,20	-12,43	10,28
Cyprus	42,81	10,01	8,44	-32,80	-1,57
Estonia	42,66	0,78	8,70	-41,88	7,91
Hungary	42,50	35,59	40,32	-6,91	4,73
Croatia	42,12	34,70	42,37	-7,42	7,67
Taiwan	41,54	25,09	50,67	-16,46	25,58
Finland	41,32	28,21	28,46	-13,11	0,26
Belgium	41,10	31,05	36,29	-10,05	5,24
Greece	39,24	2,92	0,00	-36,32	-2,92
United Kingdom	38,03	36,30	42,69	-1,73	6,39
France	37,09	51,14	56,90	14,05	5,76
South Africa	37,03	0,96	16,43	-36,07	15,47
Lithuania	36,83	34,16	30,77	-2,67	-3,39
Austria	36,46	40,86	45,01	4,41	4,15
United States	36,39	20,58	23,40	-15,80	2,82
Italy	35,88	40,44	45,36	4,56	4,92
Canada	35,80	17,87	23,90	-17,93	6,03
Malta	35,52	33,20	33,86	-2,32	0,66
Slovenia	35,10	29,30	29,13	-5,80	-0,17
Bulgaria	35,03	12,71	15,99	-22,32	3,28
Netherlands	34,13	33,89	45,74	-0,25	11,85
Latvia	32,41	30,42	30,44	-1,99	0,02
Turkey	32,05	31,29	38,88	-0,76	7,59
Australia	29,68	13,39	7,42	-16,29	-5,97
Japan	29,03	26,52	35,46	-2,51	8,94
Indonesia	28,76	39,21	59,53	10,45	20,32
South Korea	27,71	14,93	22,56	-12,78	7,64
Brazil	27,26	42,32	55,45	15,05	13,13
Mexico	26,80	30,41	41,19	3,61	10,77
India	17,94	23,54	35,97	5,60	12,43

The ranking differences are shown in Figure 16, and it is showing a clear mirroring of the EPI-PBA ranking. Despite the score differences between the PBA and the CBA being relatively small, the ranking clearly shows that developing countries like Brazil, India and Indonesia, and developed countries like France and the Netherlands are increasing their ranking. On the other hand, developing countries like China and Russia, and developed countries like Denmark, Poland and Estonia are falling in ranking. In conclusion, there is no clear trends of developing countries increasing and developed countries decreasing their ranking.

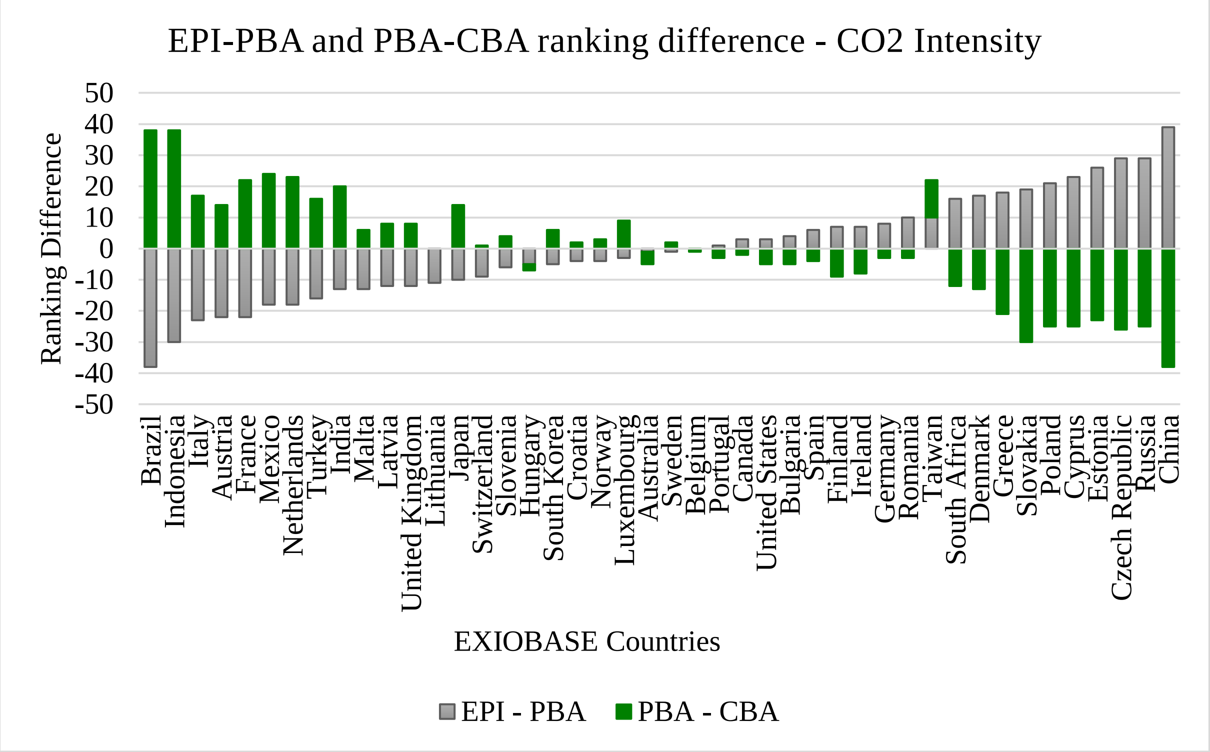


Figure 16: CO_2 Intensity ranking difference subtracting the PBA ranking from the EPI ranking, and the CBA from the PBA. The positive ranking difference means that the country has improved its ranking in the EXIOBASE indicator compared to the EPI equivalent and vice versa.

4.4.2.6. CO_2 Intensity per kWh

This indicator has the second largest number of countries outside the 30 point threshold (just behind *Forestry Land Use*) at 17 (Table 17 shows the scores and deviations). Both the green and red score deviation group contain eight countries each, while the yellow make up the remaining 11. The largest differences are seen for Cyprus, Ireland, Latvia, Malta, Norway, Portugal, and Switzerland (more than 40 points lower PBA score than in the EPI). At the same time, the largest positive shift are seen for China, Japan and France at around 30 points. The methodological differences between the EPI and PBA become apparent from the amount of countries that don't match up, which is caused by the inclusion of different sources of energy production as well as the inclusion of sectors not related to electricity production in the EXIOBASE indicator. Ideally, only the CO_2 from electricity production should be included, however this calculation includes the CO_2 from combustion for all sector. In addition only the electricity peart is included. However, comparing the calculation using CO_2 from all sectors with the calculation using only the CO_2 from electricity has almost the exact same deviations (as explained in the *Methods and Data* chapter). In conclusion, regardless of CO_2 used, the indicators don't match up as well as the *CO_2 intensity* indicator. Again, the trend element probably has a role to play in this. Also, we see that Norway which has large shares of renewable energy, has a large score deviation.

The difference between the PBA and the CBA are all within the green deviation group implying a similar carbon intensity for all countries using both PBA and CBA calculations. In general scores are slightly decreasing when shifting to CBA.

Looking at the average scores the EPI indicator is at 60,5, PBA at 46,2 and CBA at 44,1. The three data sets are fairly evenly matched with regards to tails, however, the EPI has less values below 40 than the two others, and also more values at the top end which contribute to increasing its average compared to the two others.

Table 17: Individual country scores are shown for the EPI, PBA and CBA CO_2 Intensity per kWh indicator in the order of the EPI. Negative values signifies that the country has gotten a lower score in the PBA than it had in the EPI. The colour coding signifies the level of similarity between the different methodologies. Green = less than absolute value of 10 score point difference, Yellow = between 10 and 20 absolute score point difference, Red= between 20 and 30 absolute score point difference and no colour = exceeding 30 absolute score point difference.

Country	EPI score	PBA score	CBA score	Score difference PBA – EPI	Score difference CBA – PBA
Switzerland	98,63	51,04	44,40	-47,59	-6,64
Norway	95,33	51,30	46,78	-44,03	-4,52
Portugal	90	42,52	39,26	-47,48	-3,26
Spain	89,97	62,63	60,77	-27,34	-1,86
Ireland	84,84	30,67	29,99	-54,17	-0,68
Italy	82,59	65,25	62,83	-17,34	-2,42
Brazil	79,65	75,22	72,56	-4,43	-2,67
Sweden	76,93	60,37	51,82	-16,56	-8,56
Austria	76,91	44,58	40,78	-32,33	-3,80
Mexico	73,66	60,53	58,70	-13,13	-1,84
Hungary	73,08	36,23	32,76	-36,85	-3,47
Canada	72,18	63,47	60,84	-8,71	-2,63
Belgium	70,09	44,51	42,33	-25,58	-2,18
Denmark	65,31	31,87	31,97	-33,44	0,10
Croatia	63,39	25,26	22,80	-38,13	-2,45
Finland	62,75	42,42	37,58	-20,33	-4,84
Latvia	62,58	11,80	9,18	-50,78	-2,62
Greece	61,66	29,09	29,31	-32,57	0,22
United States	60,18	90,00	90,00	29,82	0,00
Malta	59,41	0,00	0,00	-59,41	0,00
Slovenia	58,47	20,10	14,19	-38,37	-5,92
Germany	58,26	68,37	68,37	10,11	-0,01
Netherlands	57,54	48,85	48,31	-8,69	-0,54
Cyprus	57,34	0,00	0,00	-57,34	0,00
Czech Republic	54,43	35,49	34,16	-18,94	-1,32
Australia	53,98	50,59	48,07	-3,39	-2,52
Slovakia	53,21	30,24	25,29	-22,97	-4,96
India	51,91	73,37	73,04	21,46	-0,33
China	51,83	84,38	84,30	32,55	-0,09
Romania	51,58	40,16	37,83	-11,42	-2,33
Indonesia	49,45	56,31	57,14	6,86	0,83
Poland	48,99	46,60	45,72	-2,39	-0,88
United Kingdom	48,64	64,09	63,31	15,45	-0,77
Taiwan	48,45	55,02	52,43	6,57	-2,59
Russia	47,77	67,24	66,17	19,47	-1,07
Japan	43,51	74,07	73,81	30,56	-0,26
Turkey	43,4	57,21	55,60	13,81	-1,62
Lithuania	42,59	18,01	14,73	-24,58	-3,29
Estonia	42,15	3,30	2,97	-38,85	-0,33
South Korea	41,53	60,83	58,78	19,30	-2,05
Luxembourg	39,86	14,43	10,49	-25,43	-3,94
Bulgaria	39,47	26,59	24,23	-12,88	-2,36
South Africa	38,54	46,69	46,50	8,15	-0,19
France	38,23	73,80	70,07	35,57	-3,73

From Figure 17 a similar trend as seen for the other indicators is present. The largest shifts in ranking are present for the EPI-PBA transition, and only minor changes are seen for CBA-PBA. The shifts are in line with the score deviations explained above, and no clear sign of a shift in accordance with using CBA instead of PBA is apparent for this indicator.

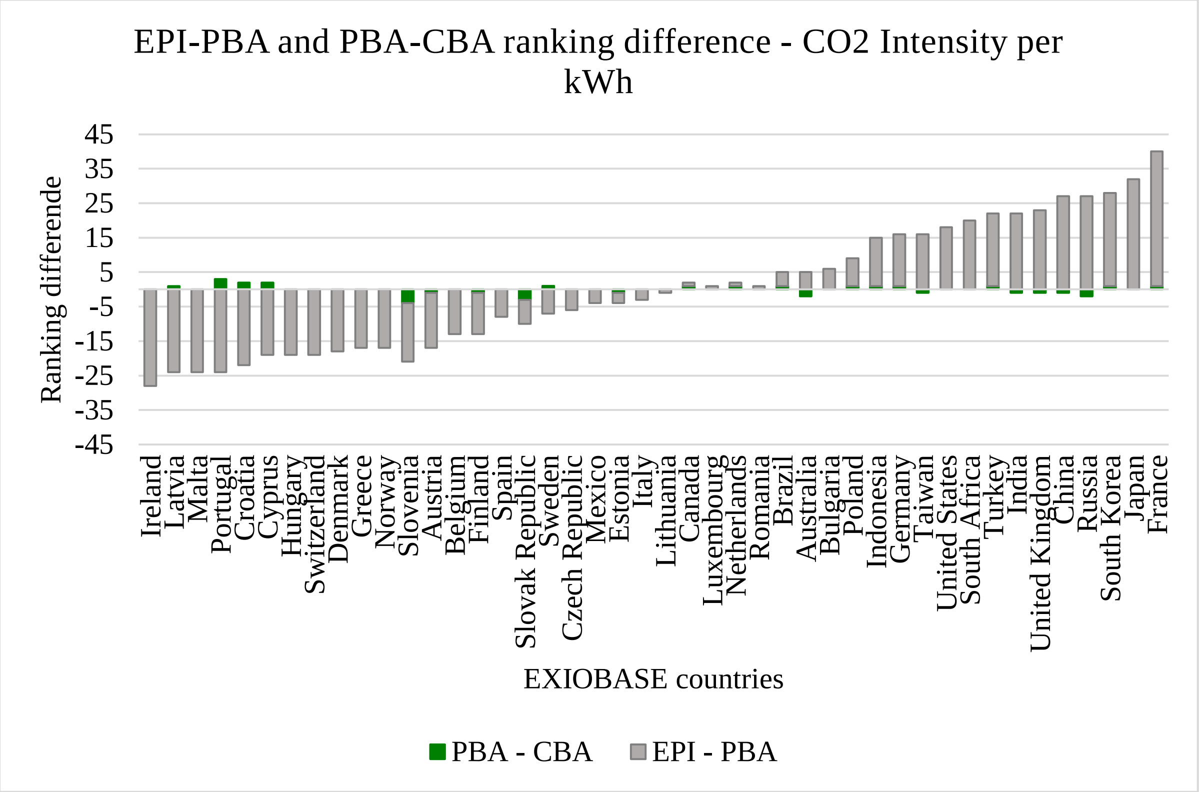


Figure 17: CO_2 Intensity per kWh ranking difference subtracting the PBA ranking from the EPI ranking, and the CBA from the PBA. The positive ranking difference means that the country has improved its ranking in the EXIOBASE indicator compared to the EPI equivalent and vice versa.

4.5. INDEX TIMELINE COMPARISON

The alternative index combining the original EPI production-based indicators with the alternative EXIOBASE indicators was calculated over time using both PBA and CBA accounts. The EXIOBASE v3 covers the period from 1995-2011, while the 2014 EPI website provides back-casted scores covering the years from 2002-2011 in addition to the values for 2012 used for the 2014 EPI calculation. These limitations results in the alternative index scores being thus calculated between 2002 and 2011. This should result in a plot of the PBA over time vs the CBA over time. The back-casted scores are found in the data file "*2014_epi_backcasted_scores.xls*" downloaded from the 2014 EPI website http://epi.yale.edu/downloads and refer *"(...) to the application of the 2014 EPI framework, indicators, and aggregation method to historic data (...)"* (Environmental Performance Indicator 2014).

4.5.1. COUNTRY COMPARISON OF TOTAL INDEX SCORES

Figure 18 displays the three calculation schemes over time. The EPI is added here to visualize its correspondence with the alternative EXIOBASE index calculations.

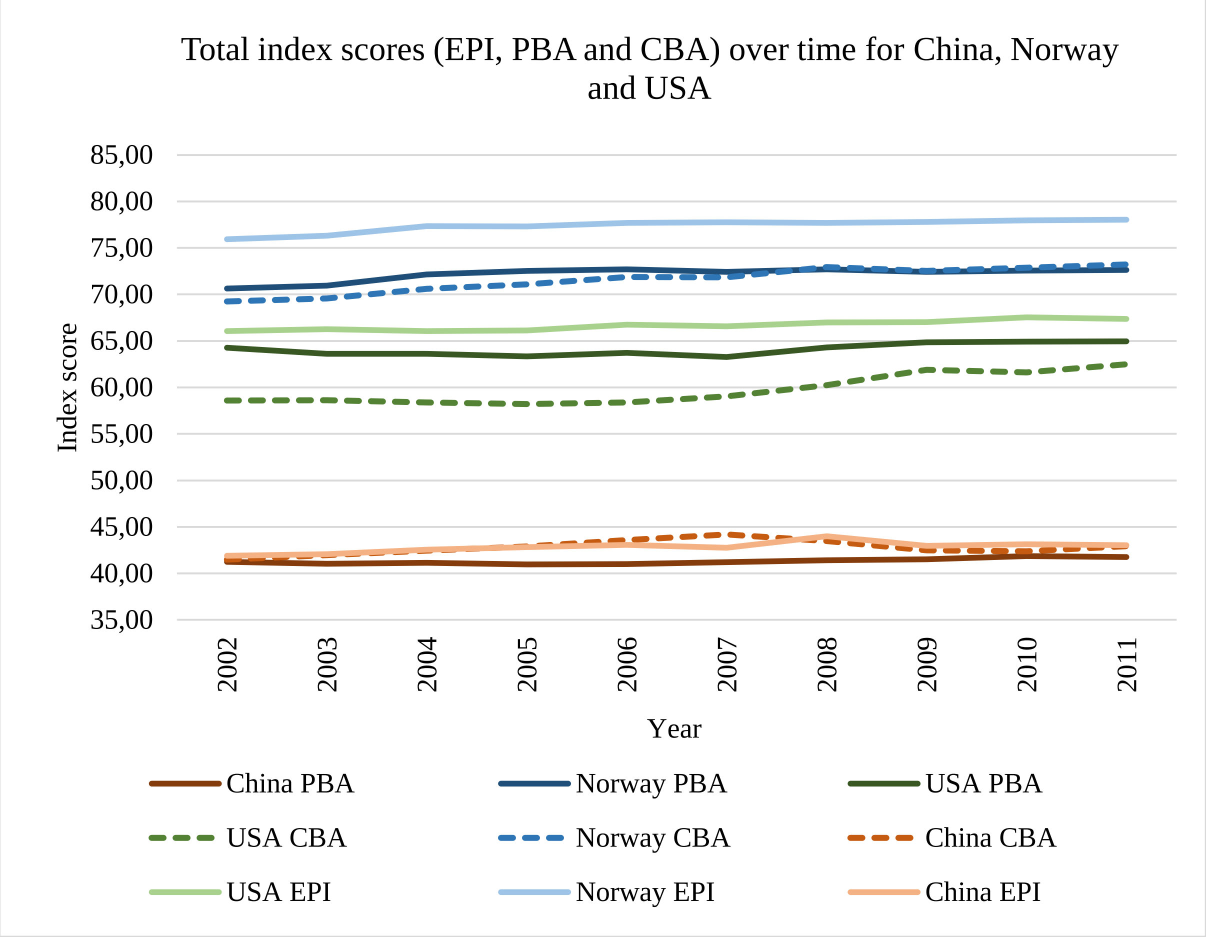


Figure 18: The three calculation schemes (original EPI, PBA and CBA) and their respective index scores between 2002 and 2011.

The first noticeable result is that the trends and values of the EPI back-casted scores are in line with the trends of the alternative EXIOBASE scores. Both methodologies yield the same ranking order for the three countries considered, where the best performer is Norway around the 70’s point range, followed by the US lying around the 60’s point range, and lastly China in the 40’s point range. The EPI scores are closer to the PBA and CBA scores of China, than in it is for the two other countries, and the EPI scores of these are slightly higher than the PBA and CBA scores

Additionally the PBA scores are consistently higher than the CBA scores for the US, while the opposite is true for China although the CBA trend line is more varying over time. A lightly different pattern is found for Norway who sees a convergence of the CBA and PBA, towards 2008, and the CBA seeming to marginally surpass the PBA score.

Norway’s PBA and CBA scores show smaller differences over the period compared to the PBA and CBA score difference of the two others countries, but the EPI is consistently around 5 points higher than the alternative index scores. A similar elevation of the EPI score can be seen for the US, although the gap is not as large as the one seen for Norway. In the US case, the largest gap is observed between the PBA and CBA scores. Chinas EPI score is much closer to the alternative index scores compared to the situation for the two other countries, and the same is true for the relatively small differences between the CBA and PBA. The average influence scores for each country in 2011 are rendered in Appendix B, which support the finding just explained. The EPI has a general higher influence score than the alternative index which results in the elevated EPI trend line.

4.5.2. COUNTRY ANALYSIS OF TOTAL INDEX SCORES OVER TIME

This section provides a more detailed analysis of the observed trends of the total alternative index scores of China, Norway and the US between 2002 and 2011. The results will be evaluated with regard to their coincidence with economic development as well as the country profile (e.g. developed or developing).

4.5.2.1. Economic Development

The economic development trends of China, Norway, and the US are shown in Figure 19. It shows that all three countries are experiencing a general increase in GDP PPP per capita over the period. Moreover, the effects of the global financial crisis of 2008 is detectible in the dip seen for both Norway and the US between 2008 and 2009. China however, has a steady increase with no apparent effect on its growth from the crisis. Comparing the GDP PPP per capita to the trends of total index scores over the same period gives insight into whether or not there are signs of impact decoupling, which will be investigated in the next three sections.

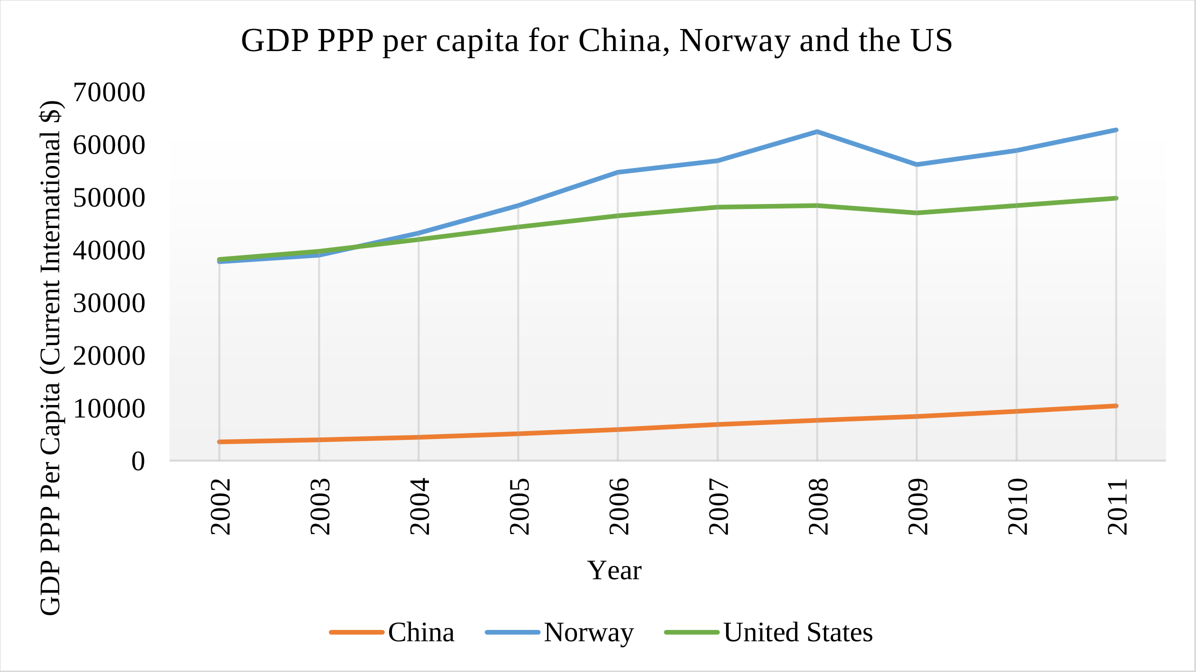


Figure 19: Economic development of China, Norway and the United States measured in GDP PPP (current international $) per capita between 2002 and 2011.

4.5.2.2. China

The PBA and CBA scores of the alternative index are shown in Figure 20 together with the economic development in GDP PPP (current international $) per capita. In general, it shows a net increase for both PBA, CBA and the economic development, with a larger net increase for CBA than for PBA. The CBA scores are constantly higher than the PBA scores which according to the methodology chapter implies that China's consumption-based impacts are lower than the production-based ones. This result is in line with the typical results found for developing countries who are net exporters (especially carbon in the case of China) (Tukker et al. 2014).

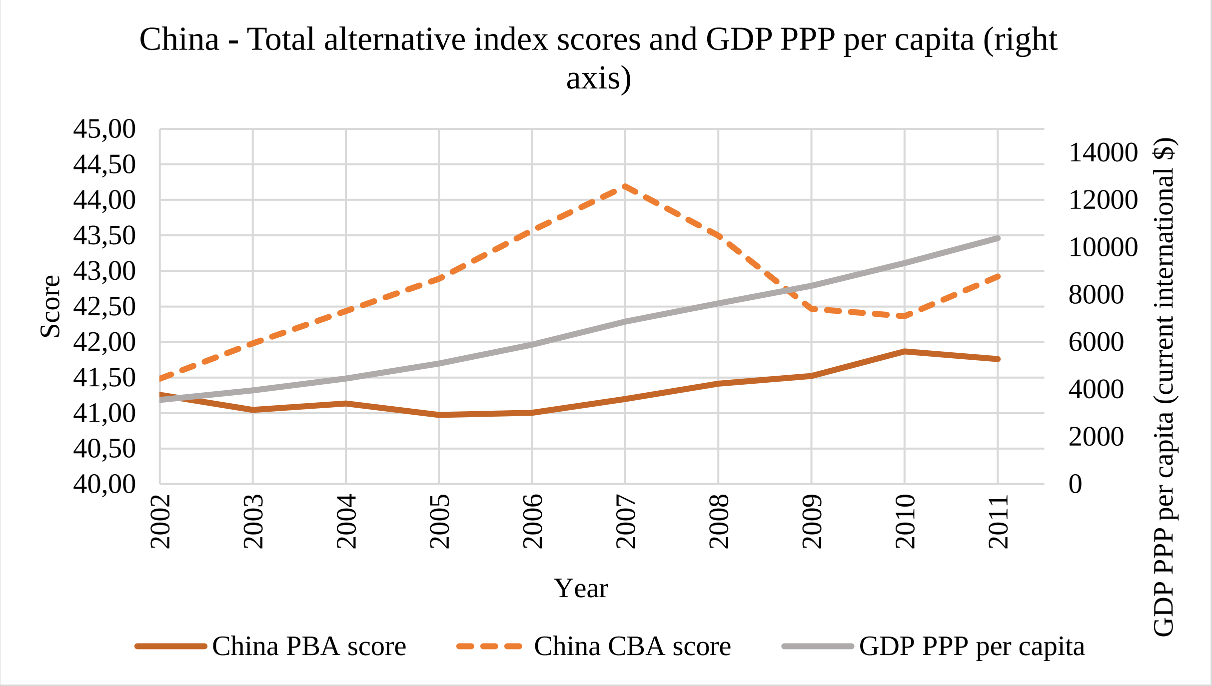


Figure 20: PBA and CBA total index scores for China, compared to the GDP PPP (current international $) per capita between 2002 and 2011.

The production-based score has a relatively stable trend line in the sense that it stays within one score point of variation. From 2005 towards 2010 a steady increase is observed followed by a slight dip from 2010 to 2011. The consumption-based scores shows a trend of much steeper increase similar to trend in the economic growth between 2002 and 2007. From 2007 it decreases towards 2010 before it increases again towards 2011. The CBA has a maximum fluctuation 2,5 score points as opposed to the PBA with less than 1 score point.

This indicates that the environmental performances of both PBA and CBA scores have improved over the period. The production-based impacts decline less than the footprints when comparing 2002 and 2011 levels and towards the end, they seem to be declining and coupling with the economic development. However, the footprint scores have a peak in 2007, meaning that the environmental impacts of the footprints were decreasing and thus decoupling from the economic development in the first part of the period. After 2007, the score declines and drops almost all the way back to the score of 2003, which means that the footprints became recoupled with the economic development after 2007 until 2009. From 2009 the impacts are stabilizing, followed by a new decrease from 2010 to 2011 implying a re-decoupling of the footprints.

It would therefore seem that the decoupling of the CBA was halted rather than reversed and that the general trend is a decoupling of the CBA. The coupling seen between 2007 and 2010 coincides with the time around the financial crisis, which suggest that the Chinese economy was affected, even though the GDP PPP shows very little sign of decline in this period compared to the Norwegian and US economies as shown in Figure 19. This is supported by Li et al. (2012) who report a drop in exports from China due to the financial crisis (Li et al. 2012).

4.5.2.3. USA

The PBA and CBA scores of the alternative index are shown in Figure 21Figure 20 together with the economic development in GDP PPP (current international $) per capita. Generally, the opposite of what was seen for China can be seen here, namely the PBA score being higher that the CBA. This translates to higher consumption-based impacts than production-based impacts which is in line with the expected result for an industrialized net importing country (Tukker et al. 2014).

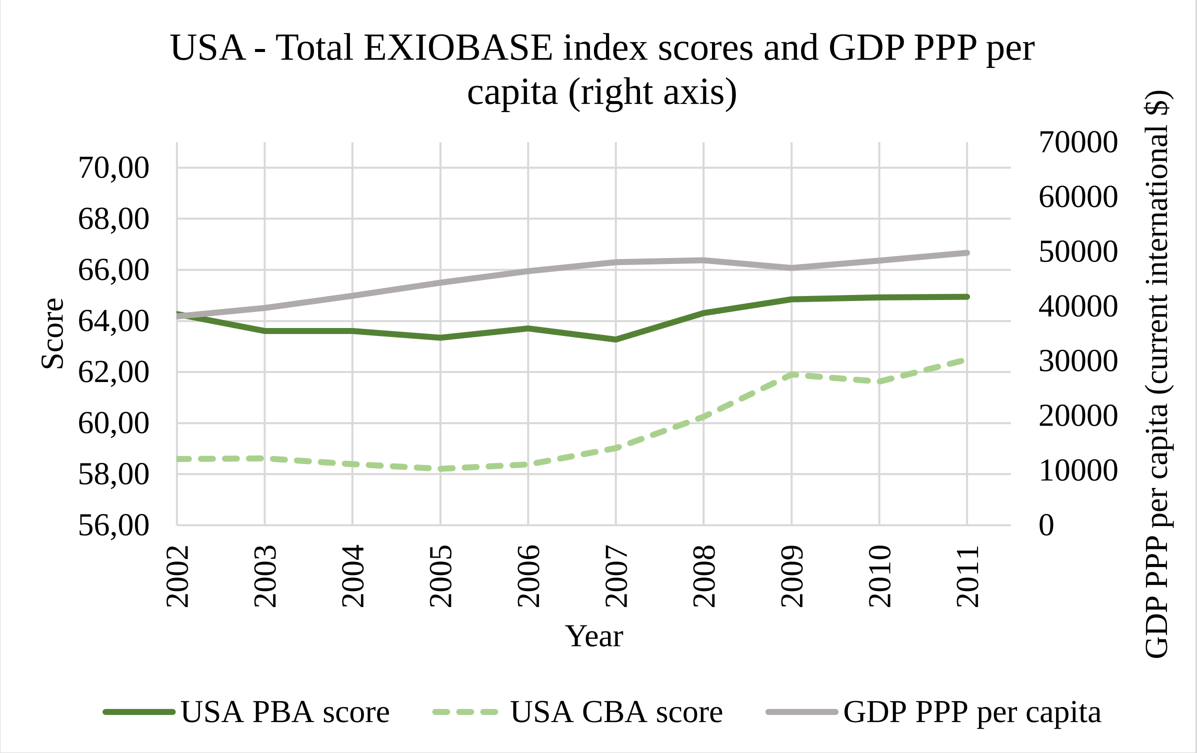


Figure 21: PBA and CBA total index scores for the US compared to GDP PPP (current international $) per capita between 2002 and 2011.

The PBA first decreases by ca. one score point with small variations between 2002 and 2007. From 2007, the PBA score increases by around one and a half points by 2009 when it flattens out and stays almost unchanged towards 2011. In total, the PBA score increases by approximately 0,7 points. The CBA has a slight decrease of 0,4 between 2002 and 2005 before it gradually increases towards 2009 where it comes to an abrupt halt and continues with a slight decrease before it increases again towards 2011. The total increase between 2005 and 2011 is 4,3 which is a relatively large increase compared to that of the PBA. This implies that both index scores of the US have improved over the period, but it is the consumption-based environmental performance that has increased the most.

The GDP PPP per capita is increasing over the period, and there seems to be a change in the coupling in the period before and after 2007 for the PBA. The PBA score is decreasing slightly before 2007, and increasing afterwards, which implies a coupling at the beginning transitioning into a decoupling from 2009 to 2011. The impacts from the CBA have decreased quite a lot compared to the economic growth, implying a decoupling between 2006 and 2011 when the slope of the CBA score is starting do increase. The financial crisis has likely caused a decrease in imports which leads to a decline in footprint impacts where a similar effect is seen in the result over time for EXIOBASE v3 and related to the recession (Stadler et al. 2017).

4.5.2.4. Norway

The PBA and CBA scores of the alternative index are shown in Figure 22Figure 21Figure 20 together with the economic development in GDP PPP (current international $) per capita. The general trends for Norway's PBA and CBA do not follow the typical profile of a developed high income country as was seen for the US. At first, the PBA score is higher than the CBA, but between 2007 and 2008 they switch places and the CBA becomes higher than the PBA. The difference between them is larger in the first period, but the shift is still atypical. This behavior may be explained by Norway's country profile. Unlike most developed countries who typically have high footprints and are net importers of land, water, material and carbon embodied in trade, Norway is a net exporter of materials embodied in trade (Tukker et al. 2014).

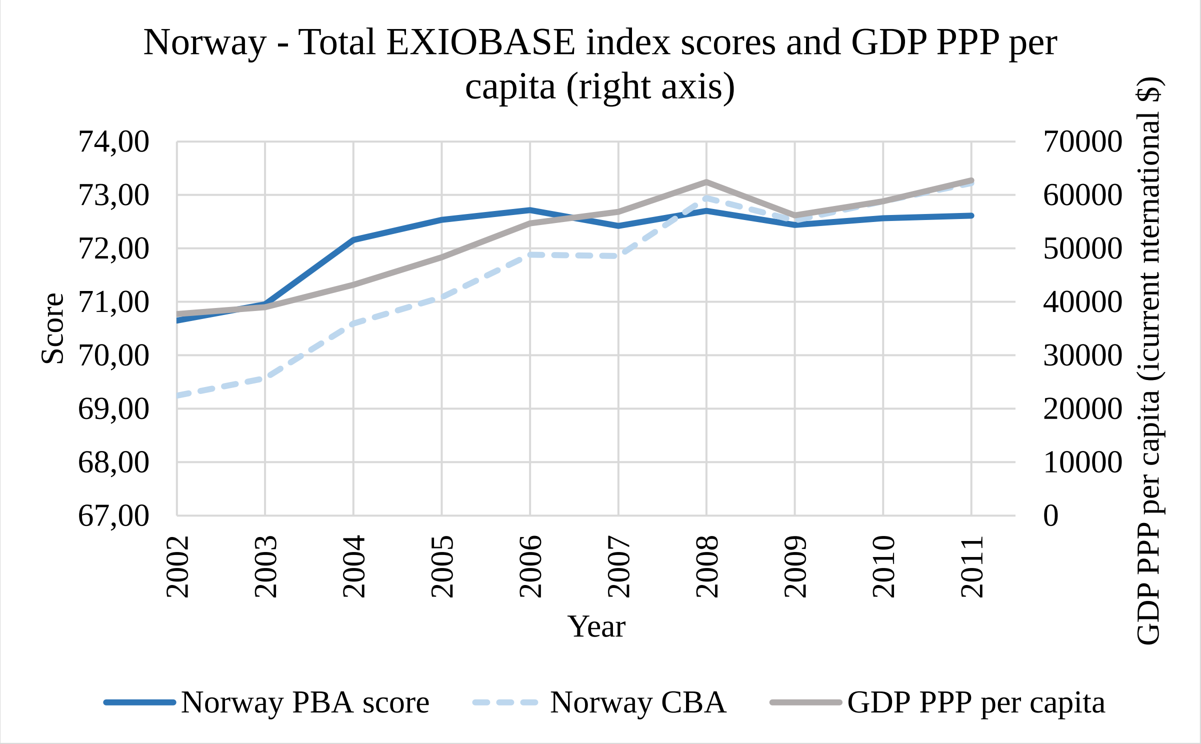


Figure 22: PBA and CBA total index scores for Norway compared to GDP PPP (current international $) per capita between 2002 and 2011.

Both CBA and PBA scores increase between 2002 and 2006. The CBA continues to increase, although variations are present between 2006 and 2009. The same variations are seen for PBA only less amplified but with a minor decrease from 2006 to 2009. From 2005 to 2011 there is a small net decrease of 0,1 score point. The CBA has a net increase over the period of approximately 4 score points, while the PBA has a net increase of approximately 2 score points. Again, the production based score is increasing slower than the CBA.

The shift seems to be happening at the time of the global financial crisis. In Norway's case, both the CBA and PBA have a relatively similar trend line compared to the GDP PPP per capita.

Both accounting schemes yield a score that is steadily increasing form 2002 until 2006 with the PBA score higher than the CBA score, the latter point being expected for a developed European country. The fact that they are both increasing with a slope relatively similar to the GDP PPP per capita implies that the economic development in this period was decoupled from the environmental impacts. However, from 2006 the PBA is slightly declining and stabilizing, while the CBA continues growing following the trend of the GDP PPP per capita. The economic growth is also slowing down 2008 to 2011, with a dip from 2008 to 2009 likely caused by the global financial crisis. Both PBA and CBA show sign of decoupling over the entire period, but the rate slows down towards the end of the period which is not unlikely since efficiency will reach a point where it can no longer increase (Steinberger & Roberts 2010; Jackson 2009).

4.5.2.5. CO_2 Intensity

Using the *CO_2 Intensity* indicator to determine the relationship between the indicator scores and the total index, as well as the findings by Stadler et al. (2017) using the EXIOBASE v3.

Figure 23 shows the same relationships between the countries as seen for the total index, with Norway as the top performer followed by the US and China.

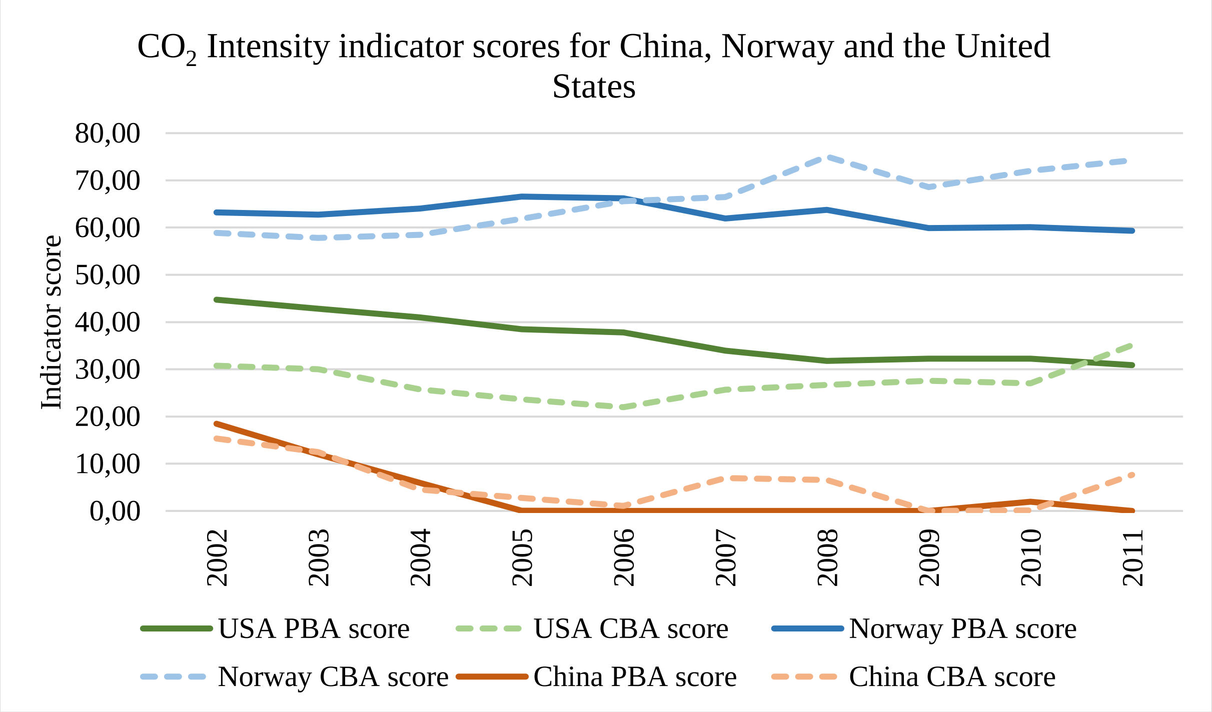


Figure 23: *CO_2 Intensity* indicator scores for China, Norway and the United States between 2002 and 2011.

The PBA score of the US is in steady decline over the period, with a slightly steeper slope between 2006 and 2008. The CBA score on the other hand is around 15 points lower and from 2002 to 2006 it follows the slope of the PBA. Between 2006 and 2008 the CBA score increases mirroring the trend of the PBA, and the two scores stabilize at a nearly flat slope until 2010 when the CBA score increases towards 2011 and crosses the PBA score. This trend is unlike the trend of the total index where both PBA and CBA scores increase over the period. The CO_2 intensity has thus decreased for the CBA impacts but increased for the PBA around the financial crisis. Comparing this result to the PBA and CBA GHG emissions (Gt CO2-eq) trends for North America calculated in Stadler et al. (2017) using EXIOBASE 3 show a similar trend as the one seen here (Stadler et al. 2017). Although this impact measurement includes additional greenhouse gases apart from CO2 it serves as the closest EXIOBASE v3 result available that can be compared to the CO2 intensity indicator. The CBA impacts are greater than the PBA impacts, and signs of the two converging are visible between 2006 and 2009 which matches the convergence in Figure 23. However the trend seen after 2009 in Stadler et al. 2017 are more similar to the trend for the total index score of the US.

China has a much more fluctuating curve than the two others, especially the CBA score, but in general both scores decrease from 2002 to 2005, where the CBA score is seeing an increase towards 2007 before it flattens out and decreases again between 2008 and 2009. From here it has a new increase towards 2011. The PBA stays around zero from 2005 to 2011 except for a small increase in 2010. Since China is the worst performer of this indicator its score is set to zero in accordance with the target methodology, thus for the years between 2005 and 2009 the exact trend is not visible. However, the account data shows that the PBA decreases from 2005 to 2008 before it increases towards 2009. This is a similar trend to what is seen for the PBA and CBA for China in Stadler et al. (2017) where the two scores diverge from around 2003 and start converging around 2007 before a parallel increasing trend can be observed (Stadler et al. 2017). However, this parallel trend is not reflected in the alternative index, where the Chinese CBA score crosses over the decreasing PBA score towards 201. The Chinese CBA score is also generally higher than the PBA score, while the opposite trend is true for the US where the PBA is higher than the CBA score. This aligns well with the findings of Stadler et al. 2017, although the cross over where China overtakes North America in impacts for both CBA and PBA is not seen for the alternative index results.

Norway has a more unusual curve, where the CBA crosses over the PBA in 2006. Before 2006 the PBA had a better score, while the opposite is the case after 2006 where the PBA score is decreasing, while the CBA is increasing and an increasing divergence is observed between the two. From having a typical developed country trend where the CBA impacts are greater than the PBA due to impacts embodied in trade, Norway's scores suggest that after 2006, the domestic activities increase in impact, while the consumption-based ones are decreasing (Kanemoto et al. 2013; Tukker et al. 2014).

Finally, the trend lines for the *CO_2 Intensity* indicator have a weighting that is large enough to make a noticeable impact on the total index, and in particular the score trends of China and Norway are reflected. The lower influence score obtained by the US (Appendix B) results in less impact from this indicator on the total index score.

5. DISCUSSION

This section provides a detailed discussion of the results. An interpretation is presented first going through the results following their order of appearance in the Results chapter. Then, based on these interpretations the research questions are addressed, before the approach of the thesis is evaluated and justified, and finally a critical review of the work is presented.

5.1. INTERPRETATION OF RESULTS

5.1.1. REPRODUCING THE 2014 EPI

The first main step in creating an alternative index based on an already existing one is to investigate its methodology in order to be able to reproduce it and apply it. The EPI provides an archive of downloadable data on its websites, and the methodology and the detailed calculations and data sources are explained in the *Metadata* (A Hsu et al. 2014a) and in "*Measuring Progress: A Practical Guide From the Developers of the Environmental Performance Index (EPI)*" (Hsu et al. 2013). The EPI thus provides transparency and a possibility of evaluating their methodologies. However, the results show that the EPI scores were not always reproducible, especially when going from data sources to creating the raw data used in the score calculations. For some indicators the data sources were unavailable, while others lacked the necessary detail to enable a recalculation. Yet others indicators like the *Change in Forest Cover* that had the necessary detail for recalculation still gave unprecise raw data results. However, being able to reproduce this step was not crucial to the further parts of the thesis since a different database would be used, thus rendering the EPI calculating methods irrelevant.

The reproducibility of the raw data on the other hand was more important, because it would indicate whether the general equation and target methodology could be replicated. The majority of the indicators could be recalculated following the EPI methodology and confidence could be put in the robustness of the approach and its transferability to the alternative index. In addition, the aggregation method used to combine the indicator scores into the total index scores was fully reproducible for all indicators with only a few exceptions in two of the *Biodiversity and Habitat* indicators. In conclusion, all the necessary steps of the EPI methodology had a sufficiently high degree of reproducibility for it to be applied to the alternative index.

Although the EPI was deemed reproducible enough to use it for the next parts of the alternative index development, there are several issues that could be improved to create a more accessible EPI methodology. In particular, the descriptions of the score calculation methodology and the principle behind the logarithmic transformation could be much more detailed to enable easier understanding of their application, perhaps with a detailed example of the general calculation method. This way, recreating the scores from the raw data would be much quicker and enhance the accessibility. The same goes for the aggregation method, which is not described in detail in the provided material.

With respect to the alpha values neither how they were deducted, nor why they were applied is explained. This would be useful to include in the documentation of the 2014 EPI methodology, especially since the wording in the *Metadata* varies between "*(...) added before transformation applied*", *"(...) applied prior to transformation*", "*(...) applied before transformation*" and simply "*alpha =1*". The description should be consistent for all indicators when the application method is the same in every case. Also, specifying how they were applied to the raw data in the score calculation would be helpful. Finally, the recalculation of the scores showed that in cases of missing values, a score was still imputed without stating how it was estimated, which is a weakness in the level of description detail .

Despite the issues described above, it is concluded that the EPI is in fact reproducible to a sufficient degree that allows for further investigation into its modification and transfer to the EXIOBASE database.

5.1.2. WEIGHTING AND INFLUENCE

In addition to the reproducibility of the score calculation, the EPI weightings are an important component necessary in the development of the alternative index since they are used for the EXIOBASE calculations. The indicator weighting of the EPI is a subjective matter based on expert opinion as well as the data quality and how well the measurement portrays the desired impact measurement. In other words (Hsu et al. 2013). The weightings of the EPI were applied directly to the alternative indicators. This means that the alternative indicators might be weighted too strongly or have their influence underestimated because the weightings were set according to the assumptions made and the limitations related to the EPI indicators.

As a result of the lacking methodology, determination of new weightings were not attempted for this study however, this is considered in the future work. A consequence of this is that the EXIOBASE indicators are directly affected by the limitations of the indicators it is substitutes. For instance, the *Agricultural Land Use* only makes out 1,5 % of the total index score due to the low weighting assigned to the EPI proxy.

Combining the weightings of the alternative indicators show that they only amount to 37 % of the total index score. This means that the remaining production based indicators of the original EPI have the largest influence on the final index score. By multiplying the indicators of the alternative index by their respective total index weightings the average influence of each indicator could calculated. Comparing the influence of the EPI and the alternative index for 2011 show a good level of correspondence for most of the indicators, however the alternative indicators have a generally higher score than the EPI. The exception is the *Climate and Energy* issue category which shows slightly lower influence than their EPI equivalents. Summing the average influence of the alternative indicators for all three calculation schemes show a maximum difference of 1,18 score points between the CBA and the PBA. The EPI score is 0,11 score points higher that the PBA. This result indicates a good correspondence in methodology between the EPI and the alternative index.

5.1.3. ANALYSING THE RESULTS OF THE ALTERNATIVE INDEX FOR 2011

The *Methods and Data* chapter describes how the alternative index is calculated and how the proposed indicators were determined. To get an impressions of the level of correspondence between the original and the alternative index, the scores for both are first presented for 2011. Investigating the snapshot results for this year help give an indication of how well the original EPI and alternative EXIOBASE methodologies line up.

By first comparing the calculation results for the total index and then for the individual proposed indicators, an evaluation can be made with respect to the differences observed between the original EPI and the alternative index. The alternative index is calculated using both production- and consumption-based accounts, and the PBA is compared to the EPI to enable a comparison of the methodologies applied. Then, the alternative index can be used to compare the results of the two accounting schemes.

The total index score results of the EPI and the PBA have a high level of correspondence which suggests that there is little effect from the alternative indicators on the total index, and substantiates the expected effect of their low combined weighing. The other comparison is made between the PBA and the CBA score of the alternative indicators, however the same high level of correspondence as for the former comparison is observed. In other words, comparing the total index scores do not offer the necessary level of detail to check for manifestations in the results caused by applying CBA indicators. To shed light on this, the individual indicator scores are compared in a similar fashion (EPI to PBA and PBA to CBA).

The result of the individual indicator examination generally showed larger deviation between the EPI and the PBA scores, than between the PBA and the CBA scores. This suggest that the main consequence of shifting to an alternative index is methodology related, and the account scheme differences become less apparent. These EPI-PBA score differences reflect the discrepancies between the original and the proposed indicator calculation method described in the *Methods and Data* chapter. Many approximations had to be made due to the lack of data correspondence between the EPI and the EXIOBASE, and the best approximations are found for the *CO_2 intensity* and *Marine Catch* indicators, followed by the PM2.5 *Average Exposure*. *Forestry Land Use* and *CO_2 Intensity per kWh* show the lowest levels of correspondence, with a majority of the countries having score deviations beyond the 30 absolute score point deviation threshold. *Agricultural Land Use* is in between, with almost as many countries within the lowest score deviation group as it has countries beyond the 30 absolute score point deviation threshold. The deviations are generally caused by measurements differences between the two methodologies, e.g. using a trend versus an absolute measure for *Forestry Land Use* and using land use per capita instead of a monetary measurement in the case of *Agricultural Land Use*. On the other hand, *CO_2 Intensity* has the highest degree of correspondence, and at the same time the best approximation of the measurement used by the EPI (kg CO_2 per GDP PPP) where the trend seems to affect the scores less than in the *Forestry Land Use* indicator. In other words, the units and data part of the alternative methodology seem to have a higher influence on the scores than the actual calculation part does.

Larger differences are found between the EPI and PBA score at the indicator level, and it is thus reasonable to conclude that the lack of score difference observed for the total index are due to the low weighting of the alternative indicators. The largest weightings are found for the *CO_2 Intensity* and *PM2.5 Average Exposure* indicators (10 % and 8,9 % respectively). The others all have weights below 6%, with the *Agricultural Land Use* indicator at only 1,5 %. This means that even though there are large differences between the EPI and the PBA scores at the indicator level, these methodological differences will not have large effect on the total index score. Similarly, the differences seen between the PBA and CBA will suffer from the same low weighting effect. Only the two indicators with weightings above 8 % will be expected to make a noticeable difference on the total index.

The deviations between the EPI and the PBA are a result of the approximations and simplifications that were applied in the alternative indicator development. The EXIOBASE has the highest level of detail among the MRIO databases currently available, and yet it lacks the appropriate stressors to perfectly replicate the EPI (Giljum et al. 2016a). However, this is not necessarily a reflection of the quality of the database, but rather its relative incompatibility with the EPI and the general problems of varying characterization and measuring purpose of environmental indicators and the confusion surrounding terminology, data and measurement methods (Parris & Kates 2003). The use of approximations would likely be necessary no matter which database were used for the development of the alternative CBA indicators, and in general the EXIOBASE provides stressors that have a high level of correlation with the EPI. The only indicator that is using a completely different proxy is the *Agricultural Land Use,* which is already given a low weighing due to EPI considerations. Although the EXIOBASE contains stressors that are similar to the units used by the EPI, the way the EPI has defined their indicators is making it difficult to apply them in the exact same way. For instance, *Change in Forest Cover* is calculated using a trend of net forest gain, so even though the EXIOBASE contains stressors for forest land use, it does not provide data on total land use up until 2002, and thus the EPI calculation cannot be replicated. Another example of this is *Fish Stocks* where the EPI measures overexploitation, while the EXIOBASE provides absolute catch data.

The general result of comparing the PBA and the CBA for each indicator showed a much higher correspondence in scores than the EPI-PBA comparison, and only the *Agricultural Land Use* indicator showed a more dispersed score deviation. The *CO_2 Intensity* and *CO_2 Intensity per kWh* indicators in addition to the *PM2.5 Average Exposure* have the highest level of correspondence with more than 31 countries within the green score deviation group. *Forestry Land Use* and *Marine Catch* also have a clear trend of high correspondence, but at the same time have countries beyond the 30 absolute score point deviation threshold, unlike the first three. The ranking order observed for the indicators using land use and carbon stressors show high correspondence with the footprint rankings found in Tukker et al. (2016) (Tukker et al. 2016).

The rankings tell a similar story, where the largest ranking differences are seen for the EPI-PBA comparison, with relatively small differences between PBA and CBA. The only indicator showing more distinct ranking differences is the *CO_2 Intensity*, with a clear mirroring of the EPI rankings. However, no clear trend of shifts in accordance with the expectations of CBA are observed, and the results could simply be caused by the tails in the scores of the PBA, which cause the EPI to be more similar to the CBA, thus mirroring the PBA rank. The *Agricultural Land Use* deviations on the other hand are in line with the shift that are expected to be observed, where developing countries are improving their score and developed countries who typically import land embodied in trade are scoring lower (Tukker et al. 2016).

In conclusion, the deviations are largest between the EPI and the PBA. This is caused by the differences in methodology used to calculate the original and the alternative indicators. Firstly the units of measurement are not the same, since the EXIOBASE does not provide the exact same measurement as was used in the EPI. In addition, the targets are having significant effect on the outcome since only one country can be scored to 100 points, in addition to the score distribution. The indicators of the EPI and the PBA generally have deviant average scores caused by tail values in the score distribution, that are not correctible even with the use of a logarithmic transformation. The modified Winsorization is also having an effect on the final scores since the countries outside the 95th percentile are automatically set to zero. This hinders an accurate score for the bottom performers, but on the other hand this is also a procedure carried out in the EPI, and is not the biggest cause for deviance in this respect. Finally, the materiality is causing differences, but is mainly an issue for *Marine Catch* since the materiality filter for forestry land use only affects Malta. However, here the main differences are present between the PBA and CBA because of the differences in the accounting schemes.

5.1.4. TIMELINE ANALYSIS FOR CHINA, NORWAY AND THE UNITED STATES

The results from the 2011 comparison between the EPI and the PBA, and the PBA and the CBA was the first step of determining whether the adapted EXIOBASE index is a good approximation of the original. To shed more light on the differences and communalities between the methodologies, and determine whether the results are reasonable and the methodology further applicable a timeline investigation between 2002 and 2011 is conducted.

In general the three countries (China, Norway and the US) align with the EPI, which means that they are reasonably ranked with Norway as the best performer followed by the US and China. The PBA score is as expected higher than the CBA for the US, and opposite for China (Kanemoto et al. 2013). The EPIs scores are consistently higher for both Norway and the US, while China's trend lines are more similar. The difference seen for China could be caused by the target methodology setting China's score to zero and the actual variations in the PBA score are not visible. The difference between the EPI score and the alternative scores is definitely highest for Norway compared to the other two countries. This is likely caused by the effect of the denominator used combined with the target methodology, which cases a country like Norway with a relatively small population to become the worst performer per capita. This is especially true for *Marine Catch*, where Norway is a clear outlier and is set to zero, and is likely causing Norway to have a higher EPI score compared to the alternative index. The differences seen between calculation schemes are reflected in each country's total average influence score for 2011 (Appendix B) which shows that the EPI has a higher total index score than the alternative index for both Norway and the US.

The results from the 2011 comparison suggest relatively small differences between the PBA and CBA scores. However, looking at each country shows the true variation of the scores, and in the case of the total index, the CBA and PBA scores are converging towards 2011 which explains the smaller differences in the findings for 2011. Furthermore, both PBA and CBA scores have net increase between 2002 and 2011, which means that over all, the alternative index results suggest that the environmental performance has generally improved. It must be emphasized that this is the net trend, and over the period the countries have clear fluctuations. In addition, a manifestation of the global financial crisis is present for all three countries, but at varying degree and with different outcomes.

China's CBA score is higher than the PBA score for the entire period (although with some variations), which is in line with what one would expect from a developing country with large amounts of export. The USA represents the opposite case where the PBA is higher than the CBA score over the entire period, which is the expected result for a developed country (Davis & Caldeira 2010; Kanemoto et al. 2013). The majority of net exports from China are consumed in Europe and the US. The CBA and PBA scores of China and the US reflect this trade correlation, where China is a net exporter, while the US is a net importer (Tukker et al. 2014; Tukker et al. 2016). As mentioned, the effects of the global financial crisis is visible in all the alternative index scores over time. Although the economic growth of China seems to have little or no set back cause by this compared both Norway's and the US's GDP PPP per capita trends, the effect is clearly visible in China's CBA trend line. While the Chinese PBA score stays fairly stable with a slight net increase over time, the CBA score is increasing at a much higher rate from 2002 to 2007. However, from here it decreases again with a similar negative slope just around the time of the financial crisis. At the same point in time, the US had an increase in both PBA and CBA scores, implying that their environmental impacts went down, i.e. their consumption per capita dropped, as would be expected in a recession. This drop in consumption is the opposite of what is happening to the Chinese CBA curve. The drop in US imports causes a decrease in the Chinese exports (Li et al. 2012) of which a major part is destined for US consumers, as previously explained. China's decreased export led to decreasing the gap between domestic production impacts and impacts from final demand, which can be seen from the CBA trend line over time.

The alternative scores observed in Norway's case are standing out with the CBA crossing over the PBA score between 2007 and 2008. In other words, the effect of the financial crisis seems to be affecting Norway differently than the other developed country example (the US). This could be caused by Norway's status as a net exporter of materials embodied in trade, as opposed to the typical net importer profile seen for other developed European countries (Tukker et al. 2014).

5.1.5. CO_2 INTENSITY INDICATOR EXAMPLE

The trend results for the three countries suggest that the alternative index is indeed reflecting findings in other research done using the EXIOBASE 2.1 (Tukker et al. 2014). Furthermore, a detailed look at the indicator level using the largest weighted *CO_2 Intensity*, reflects many of the trends seen for the total index. Although, as expected, the effects are more distinct at the indicator level than for the total index, it does suggest that the alternative indicator is having a noticeable effect on the total index. In particular, the CBA trend of China at the index level are reflected in the CBA curve of the *CO_2 Intensity*, which has a similar incline and decline between 2006 and 2009. In Norway's case, the crossing of the CBA and PBA score trend lines is also present yet much more distinct for the indicator, than for the total index. The US is the only country with a slightly dissimilar trend line, especially for PBA which deceases, as opposed to the increase seen at the index level. This lesser correspondence between indicator and index for the US is reflected by the influence scores for PBA, which are around half of the EPI influence for this indicator. In conclusion, many of the trends seen at the index level are reflected in the CO2 intensity indicator due to its relatively high influence compared to the other indicators.

Comparing the results of the *CO_2 Intensity* indicator to the findings by Stadler et al. (2017) allow for an evaluation of how well the alternative indicator methodology depicts other research done using the same database. This allows for an interesting comparison and similar results found for this thesis and the EXIOBASE v3 study would suggest that the alternative index is yielding reasonable results. However, the study uses an absolute impact measure, and the *CO_2 Intensity* is calculated per GDP PPP, hence the two results are not exactly comparable. On the other hand, the GHG emissions (Gt CO2-eq) calculated by Stadler et al. (2017) provide the closest approximation to the CO2 intensity indicator calculated using the EXIOBASE v3 (Stadler et al. 2017). Comparing the two trend lines is thus applied as a pointer to possible similarity between them. Again, taking care to distinguish between scores and impacts is important for the analysis, as explained in the *Methods and Data* chapter.

First of all, the EXIOBASE v3 results show that the PBA impacts of the developed countries (North America and EU-27) are lower than the CBA impacts which is expected for net importing countries, where the impacts embodied in trade are causing the CBA to surpass the

CBA. China is showing the opposite, with CBA impacts lower than the PBA impacts, suggesting lower footprints when impacts embodied in trade are allocated to the consumer (Kanemoto et al. 2013). This is reflected in the scores of the CO2 intensity indicator, for both China and the US with higher PBA scores than CBA scores for China and vice versa (with scores being the inverse of impacts for the alternative indicators).

The divergence and convergence seen for the PBA and CBA scores of China in the CO2 intensity indicator, are also observed in the EXIOBASE v3 results, however, the increase in impacts seen for the latter is not as sharp in the alternative indicator. The problem of target methodology reappears, with the PBA score set to zero between 2005 and 2009 since China is the lowest performer of the 44 countries. However, the raw data reveals that there is indeed a presence of the divergence and convergence just described for the GHG impacts. In the EXIOBASE v3 results, both the Chinese PBA and CBA impacts are surpassing the impacts of both North America and EU-27. This represents a difference between the study and the thesis results, where the is a sharp increase of Chinese GHG impacts as opposed to the net decrease in impacts for the *CO_2 intensity* indicator. In other words, the relationship between the CBA and PBA is similar for the scores and the EXIOBASE GHG impacts, but they show different trend with respect to impact increase and decrease. This could be caused by the difference in measurement used (Stadler et al. 2017).

The GHG impact trends for both EU-27 and the US show very similar trend lines, which are both converging and decreasing from 2007 towards 2009 due to the global financial crisis (Stadler et al. 2017). The convergence can be traced in the *CO_2 Intensity* score results for the US between 2007 and 2010, however Norway is showing an atypical trend curve compared to the EU-27. This, it may be concluded that Norway is not a good representative for a typical European country due to its net material export embodied in trade.

In conclusion, both China and the US are showing score values that share similarities with the results in Stadler et al. (2017), although China's differing slope makes the comparison somewhat inconclusive. Norway is still more similar to the alternative index scores that to the GHG impacts of the EXIOBASE v3 and thus not a good representative for EU-27. Considering the differences in measurement, the results of the CO2 intensity score trend line and the GHG impact trend, the similarities observed are promising with regards to the alternative indicator being representative for findings done in other research. This is also encouraging for the overall results of the alternative index in that the score results are reflective of historical impact trends observed as well as other research.

5.1.6. SIGNS OF DECOUPLING

In addition to comparing the trend lines to each other, comparing them to the economic development gives an indication of the presence of decoupling. In general, all countries are showing decoupling, but to different degrees. The CBA scores for all three countries are also showing a steeper slope compared to the PBA slope. This is a plausible result, because it signifies that the domestic production stays relatively stable, and that the imports are more fluctuating.

In China's case, there is evidence of absolute decoupling from 2002 to 2007, where the score suggests a recoupling with the economic development. However, from 2009 the trend shows a stabilization and the decoupling is resumed towards 2011. This suggests that the decoupling is merely put to a temporary halt in connection with the consequences of the global financial crisis.

The decoupling observed by (Ward et al. 2016) between 1990 and 2012 only suggests the presence of relative decoupling for China, however, the findings of the alternative index are still in line with the general trend observed, only the magnitude of the decoupling is different. The relative decoupling trend seen for China is a sign of technical developments and thus an increased efficiency (Jackson 2009). As a developing country, China would also be expected to have more room for improvement related efficiency and environmental impacts compared to already developed countries.

The US is also showing signs of absolute decoupling for both PBA and CBA, however, the CBA is again at a steeper slope than the PBA. The decoupling seems to start around 2006, and continues towards 2011. The OECD showed a flattening of energy and material consumption between 1990 and 2012 according to Ward et al. (2016), and thus an absolute decoupling is observed which coincides with the observed score result for the US (Ward et al. 2016).

Norway has the clearest signs of decoupling among the three example countries, and starts already from 2002, however it flattens out between 2006 and 2011 for both PBA and CBA scores. This may indicate that the efficiency levels have reached a level where they are no longer contributing to significant new improvements, which is not unlikely for a highly developed county. The rebound effect may also play a role in the stabilization of the scores in the way that increased efficiency is counteracted by increased consumption (Steinberger & Roberts 2010; Jackson 2009)

The general decoupling observed in the PBA and CBA scores for all three countries are also in line with the gradual decoupling of energy and carbon from human needs observed by Steinberger & Roberts (2010) (Steinberger & Roberts 2010) This further suggests that, although the decoupling observed in China's scores are slightly more optimistic than the ones found by Ward et al. (2016), the general picture provided by the alternative index is in line with findings from other research. This adds to the credibility of the alternative index scores.

5.2. ANSWERING THE RESEARCH QUESTIONS

The four research questions posed in the Introduction will be addressed in this section.

- Is the 2014 EPI methodology reproducible?
- Can the 2014 EPI index and the EXIOBASE v3 database be combined into an alternative index?
- Does the alternative index produce reasonable results in terms of timeline evaluation, and are there signs of decoupling from economic development?
- Based on the findings, is the alternative index recommended for sustainability assessment?

The first seeks to assess the reproducibility of the 2014 EPI methodology, and is a crucial step for the further investigations in this study. It is found that the weighting and aggregation methodology was exactly reproducible apart from minor differences found for the *Terrestrial Protected Areas (national and global biome*) indicators, and the effects of rounding the score values. However, the scores had varying degrees of reproducibility. For the majority of indicators, the recalculated scores based on the provided raw data were found to be exactly equal to, or within acceptable range of, the EPI scores. Among the EPI indicators used for CBA conversion, *Coastal Shelf Fishing Pressure* and *Trend in* CO_2 *Emissions per kWh* stood out as least reproducible. Producing the raw data from the data sources also proved difficult for most of the indicators. In other words, all the steps of EPI indicator development were not possible to replicate, but the parts of the methodology with significance for the alternative indicator development were. In general the raw data produced the scores when applied to the proximity-to-target equation (Equation (2)), and the aggregation was perfectly reproducible for the relevant indicators. This gives the necessary confidence in the EPI methodology to be able to put it to use in the next steps of this study.

The question of whether the 2014 EPI index could be combined with the EXIOBASE v3 relies on the data availability and similarity of the latter, and how well it corresponds to the intended indicator measurements of the EPI. Even if the EXIOBASE provides a high level of sectoral and product detail, it may not correspond exactly to the EPI data or units. Moreover, the methodology applied in the EPI relies on targets, which in some cases are impossible to transfer to the alternative indicator due to the stressors used for calculation. Only the *CO_2 Intensity* indicator could replace its EPI equivalent using the same unit, and even then, the calculation deviated from the EPI due to its use of a trend.

The stressors used to substitute the EPI data are all in accordance with the absolute measure of the EPI except for *Agricultural Subsidies*, which is replaced by land use stressors. The results from the 2011 evaluation show that there are noticeable differences between the EPI and the EXIOBASE calculated using PBA. However, these differences are common to both the PBA and the CBA calculations, and despite the inability to perfectly replicate the EPI indicator measurements, the EXIOBASE indicators are applying the stressors that yield the best approximation to the EPI indicators. In other words, the EXIOBASE can be combined with the EPI, but as is expected for any attempt to apply new data to an existing methodology, differences are unavoidable and approximations are necessary.

Although the EPI and the EXIOBASE can be combined into an alternative index, the results from the 2011 comparison shows relatively small differences between the PBA and CBA calculations and non-conclusive results with respect to its advantage as a consumption-based index. The timeline calculation of the total EPI, PBA and CBA index scores show that for both China, Norway and the US the alternative index to a large degree follows the EPI's trend. A closer look at the individual countries reveals a much greater variation which allows for a detailed evaluation of the trends and how well they match real events. For all three countries, the scores are generally increasing, and all see the effects of the global financial crisis of 2008. Reasonable trends related to expectations of difference in environmental performance for CBA and PBA are found for all three countries, where the US is scoring better at PBA than at CBA, and the opposite is true for China. Norway is showing a more ambiguous curve, but it is likely caused by the country's atypical profile as a net exporter of materials embodied in trade (Tukker et al. 2014). Furthermore, the decoupling observed is in line with the findings of general global decoupling, and specifically the absolute decoupling observed for the OECD (Ward et al. 2016; Steinberger & Roberts 2010). Hence, it can be concluded that the alternative index is providing plausible and reasonable results with regards to both PBA versus CBA timeline considerations and decoupling trends. At the indicator level, the results of the *CO_2 Intensity* indicator timeline calculation shows good resemblance with the findings of the EXIOBASE v3 results. These trends of this indicator are also detectible in the total index timeline scores, which is expected based on its influence scores.

Based on these findings, it can be concluded that the alternative index does provide reasonable results both at country and indicator level. However, the EPI production-based indicators dominate the total index scores, and for the alternative indicators to have an impact the weightings need to be adjusted. In this respect, further investigation should be conducted at the indicator level to determine how to augment the weightings and influence of the alternative indicators. In its current state, the alternative index is applicable for sustainability assessment, but it does not yet provide a fully comprehensive alternative to the EPI and needs further improvements in addition to the ones mentioned above. In particular, the targets should be improved to allow for more than one country to obtain a top score and also to becoming more realistic with regard to sustainable consumption levels. For instance, the indicators measuring land use, marine catch and CO_2 emissions could apply targets like the ones suggested for carbon and water footprint by Tukker et al. (2016), set per capita consumption in 2050 (Tukker et al. 2016). If these improvement were possible to accomplish, the alternative index could provide an improved and more accurate measure for environmental performance and an improved tool for decision-making towards a sustainable future.

5.3. JUSTIFICATION OF THE APPROACH

The approach of this thesis is based on the 2014 EPI methodology, and one of the goals was to establish the consequences of switching out the EPI data sources with an alternative database. To do this, the EPI methodology was modified to fit the available stressors of the EXIOBASE. AS the results show, the approximations caused noticeable differences in score values between the EPI and the alternative index which were mainly caused by the target and weighting methodology used to calculate the EXIOBASE indicators. However, the weightings were kept in their original for to be able to assess their initial impact on the result. Only after this initial assessment, could a changing be considered, and since the main focus of this thesis has been on the EPI framework, alternative weightings would need additional assessment of the EXIOBASE data, which was not included in this thesis. The weighting is suggested for the future work.

The targets were simplified to be applicable to all the EXIOBASE indicators, and in order to make the methodology differences between the PBA and CBA calculations as small as possible. However, compared to the EPI the targets are not well suited to assess the top performance of more than one country. Because of the difference in measurement applied by the EPI, and the difficulties of replicating these using the EXIOBASE, the targets were not individually set since the indicators themselves would not perfectly match each other anyway. Thus, the differences in calculation methodology made it difficult to reproduce a target for the EXIOBASE similar to the EPI target, and the general methodology described in Methods and Data was deemed the best choice for this thesis. However, target improvement is suggested for the future work.

The materiality filters used by the EPI were only relevant for *Forestry Land Use*, and *Marine Catch*. In the first case, only Malta was affected and the materiality was applied to the PBA. However, for the *Marine Catch*, only the materiality filter for the landlocked countries was applied due to the differences in data sources used by the EPI and the EXIOBASE.

5.4. LIMITATIONS

Since the EPI is providing the main framework for this thesis the focus is mainly on the EPI methodology. However, a more detailed investigation and a fuller understanding of the implications of the EXIOBASE data and calculations methods may have been beneficial to increase the understanding of the results, and the differences observed.

More countries and indicators could have been investigated over time to uncover more trends, especially since Norway proved to be less representative for the European countries. Choosing a more typical EU-27 country may have increased the conclusiveness of the results.

The *CO_2 Emissions per kWh* indicator was calculated using the stressor for CO_2 from combustion. However, it should have been decomposed to only include the relevant sectors for electricity production. Although the results from testing this selection for 2011 showed only few differences for most of the countries, the affected countries showed relatively large deviations. Thus, the results from this indicator are not a good match for the EPI measurement, and yields a deficient presentation of the CO_2 intensity of electricity production. For the current index, it only amounts to 5% of the total index so the consequences are diminished, but if the weightings were to be adjusted (increased) this would give a wrongful measurement.

The target methodology of the alternative indicators result the worst performers are set to zero. This makes it difficult to see the actual variations in score over time since the affected countries are set to the same value (zero) each year.

The EXIOBASE only evaluates 44 countries in detail, and the rest are grouped in rest of world regions. This means that the level of detail provided in the EPI is lost, and the omitted countries thus lack the possibility of comparing their environmental performance to their peers. However, the largest economies are represented by the EXIOBASE counters (making up 95 % of the world economy), and mainly European counties. In a consumption based perspective, these are also the main importers of impacts embodied in trade (Giljum et al. 2016a; Tukker et al. 2016), and so tracking their impacts is covering the major trade flows necessary for a comprehensive global sustainability assessment.

6. CONCLUSION

In this this thesis an alternative consumption-based index has been developed. The goal of the index was to serve as an alternative to the EPI for a more comprehensive tool in sustainable decision-making.

The EPI framework was used as basis for the alternative index, and it was found that the degree of methodology reproducibility was satisfactory for further application. Most scores were successfully reproduced from the raw data using the provided methodology descriptions, and although the data sources were less reproducible they were not crucial to the development of the alternative index. The aggregation method was fully reproducible, except for a few countries in one EPI indicator, and the weightings could readily be applied to the alternative index.

The results of comparing the EPI and the alternative index of 2011 showed that there were generally more significant differences between the results of the two methodologies, than between the accounting schemes. This was mainly due to the difference in target methodology, but also because of the difference between the EPI measurements and calculation method, and the alternative method applied to the EXIOBASE indicators. In addition, the low combined weighting of the alternative indicators (37%) caused them to have less influence on the total index score. Methodological differences emerged due to the many approximations made to adapt the EXIOBASE stressors to the EPI.

Investigation of the index scores between 2002 and 2011 for China, Norway and the US showed generally increasing CBA and PBA scores, which means an improved environmental performance overall. The trends for China and the US coincide with the expected relation between production- and consumption-based accounting, i.e. higher CBA scores than PBA scores for China, and vice versa for the US. Norway was a particular case where the CBA score crossed over the PBA score after the financial crisis. This may be due to Norway’s net export of materials embodied in trade. All countries display an effect caused by the global financial crisis of 2008, where the US’s CBA score is increasing while the opposite is happening for China, which is a sign of the trade correlation between the two, and the effect of the drop in US imports on China’s economy.

Examination if the trend using the CO_2 intensity indicator holding the highest weighting among the alternative indicators, showed more amplified versions of the trends seen at the index level for both Norway and China. The US trend line had less similarities with the index, but at the same time it showed less signs of influence on the index. This result was also reflected in its lower influence score for the *CO_2 Intensity* indicator. Furthermore, the timeline scores of China and the US showed similarities with the GHG emission impacts found for the EXIOBASE v3 (Stadler et al. 2017), however this was not the case for Norway. In other words, Norway is still not following a typical developed country profile. Moreover, the difference in impact measurement makes the EXIOBASE v3 comparison more ambiguous, but the points of similarity found for China and the US indicate that the alternative indicator is giving reasonable results.

All countries show signs of absolute decoupling, although the findings from Ward et al. 2016 suggest that China has only had a relative decoupling between 1990 and 2012. The flattening of the score trend observed for Norway suggests that the efficiency is no longer increasing at the same rate as seen for the two other countries. China and the US this have higher potentials for further decoupling as opposed to Norway.

Overall, the alternative index is showing reasonable results in line with other research and real life events (e.g. the global financial crisis of 2008) implying that the results are robust. However, if the index is to be applied further, the weightings need to be redistributed to accommodate the alternative EXIOBASE indicators, and the target methodology needs to be further improved to better measure country performances.

The EPI is already used by policy makers as a tool for decision making and integrating CBA into an already well known index could provide a more accurate sustainability measurement in this respect. However, in its current state, the indicator is not yet a full and ready-to-use index due to the limitations related to the weighting and targets. Further research is needed to adjust the weightings appropriately to fit the EXIOBASE indicators. The targets are also in need of further investigation to allow for more than one country to receive the top score.

In conclusion, the alternative index is suffering from the methodological differences observed, but still shows promising sings of accurately depicting the effects of switching accounting schemes (PBA to CBA). In other words, if improvements were made to the weightings and targets, such a consumption-based index could provide policymakers with an improved tool for decision-making, and thus contributing to a sustainable future with continued decoupling of environmental impacts from the economic development.

It is recommended to continue the development of the alternative index with a focus on targets and weightings in order to provide a robust consumption-based index that can be considered realistic alternative to the EPI

7. SUGGESTIONS FOR FUTURE WORK

Through this work, several suggestion for future work have emerged, and will be presented below.

The alternative index would benefit from redistributing the weightings which are currently based on the EPI weightings. This would allow for a more appropriate influence on the total index score from the proposed consumption-based indicators.

The proposed EXIOBASE indicator replacing *Agricultural Subsidies* is currently only measuring agricultural land use for crops and permanent pasture. However, increasing the weighting of the *Agriculture* issue category would allow for the inclusion of several EXIOBASE indicators instead of just one. This way, stressors for both water use, ecotoxicity and eutrophication could be included as additional indicators providing a better measurement of impacts from agricultural activities and at the same time cover the rationale for inclusion of the EPI indicator.

The general methodology applied to the proposed indicators sets the targets to either best or worst performer, where a modified Winsorization is applied in the case of outliers. However, this means that the top spot is restricted to a single country even though there may be several countries that merit a top performance score as is done for the EPI. To overcome this problem and further approximate the proposed indicators to the original EPI, modification of the targets is suggested for future improvements of the alternative index. For instance, instead of applying the best performer principle to the *Marine Catch* indicator, a target of sustainable catch amount would be more reasonable. The current target results in a top performer than might consume less than what is both environmentally and economically sustainable, which is not ideal. On the other hand, creating such a target would require regional data on both sustainable catch levels and diets, and implementing them may not be practical considering the issues of aggregating data present in MRIO analysis.

The same argumentation is applicable to both the proposed indicators measured by land use stressors, and the agricultural land use in particular. Using a target similar to the one suggested by Tukker et al. (2016) could result in a more nuanced and descriptive image of the actual land use situation and the performance of each country. By setting a target of average sustainable land use per capita according to the total available land left for expansion which is estimated to 1,5 million km^2 according to Tukker et al. (2016) (although the citation for this was not successfully retrieved, the general idea is still viable) the indicator would give a better picture of the level of sustainability for each country (Tukker et al. 2016).

As explained in the limitation of the thesis approach, sorting out the CO2 from combustion related only to the electricity use sectors of the EXIOBASE would provide a better approximation to the EPI.

In light of the complications of developing different target, a simpler alternative might be to apply a rescaling to get scores more aligned with the EPI scores. Using the top score of the EPI to rescale the EXIOBASE PBA scores would provide better matching score vales, but the problems related to tail values would still be present. This might have to be accepted as the result of discrepancies occurring when merging two different methodologies, however, it would decrease the deviation between the 2014 EPI and the EXIOBASE PBA scores.

Finally, as mentioned in the methodology, the EPI 2016 is using standardized indicator measurements (i.e. per capita of per GDP) which is more in line with the methodology applied to the alternative index. In light of this and the findings of this study suggesting a moderate to low level of correspondence between the EPI methodology and the EXIOBASE database, the 2016 EPI may be a better fit.

8. REFERENCES

Acquaye, A. et al., 2017. Measuring the environmental sustainability performance of global supply chains: A multi-regional input-output analysis for carbon, sulphur oxide and water footprints. *Journal of Environmental Management*, 187, pp.571–585.

Alliance for Zero Extinction, 2005. Zero Extinction - Home. Available at: http://www.zeroextinction.org/ [Accessed October 10, 2015].

Anderson, K., 2009. Distorted Agricultural Incentives and Economic Development: Asia’s Experience. *World Economy*, 32(3), pp.351–384.

Anderson, K. & Nelgen, S., 2013. Updated National and Global Estimates of Distortions to Agricultural Incentives, 1955 to 2011. Available at: www.worldbank.org/agdistortions.

Bonjour, S. et al., 2013. Solid Fuel Use for Household Cooking: Country and Regional Estimates for 1980–2010. *Environmental Health Perspectives*, 121(7), pp.784–790. Available at: http://apps.who.int/gho/indicatorregistry/App_Main/view_indicator.aspx?iid=2267.

Böhringer, C. & Jochem, P.E.P., 2007. Measuring the immeasurable — A survey of sustainability indices. *Ecological Economics*, 63(1), pp.1–8. Available at: http://www.sciencedirect.com/science/article/pii/S0921800907002029 [Accessed July 13, 2014].

Center for International Earth Science Information Network - CIESIN et al., 2011. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Population Count Grid. Available at: http://dx.doi.org/10.7927/H4VT1Q1H [Accessed December 29, 2016].

CIA World Factbook, 2013. The World Factbook. Available at: https://www.cia.gov/library/publications/the-world-factbook/ [Accessed September 29, 2015].

Davis, S.J. & Caldeira, K., 2010. Consumption-based accounting of CO2 emissions. *Proceedings of the National Academy of Sciences of the United States of America*, 107(12), pp.5687–92. Available at: http://www.pnas.org/content/107/12/5687 [Accessed November 23, 2015].

Desha, C., Hargroves, C. & Smith, M.H., 2010. *Cents and Sustainability : Securing Our Common Future by Decoupling Economic Growth from Environmental Pressures* C. Hargroves & M. H. Smith, eds., London: Routledge.

Dietzenbacher, E. et al., 2013. The Construction of World Input–Output Tables in the WIOD Project. *Economic Systems Research*, 25, pp.71–98.

Dixon, W.J. & Yuen, K.K., 1974. Trimming and winsorization: A review. *Statistische Hefte*, 15(2), pp.157–170. Available at: http://dx.doi.org/10.1007/BF02922904.

van Donkelaar, A. et al., 2015. Use of satellite observations for long-term exposure assessment of global concentrations of fine particulate matter.(Research). *Environmental Health Perspectives*, 123(2), p.135.

Environmental Performance Indicator, 2014. Our Methods: Environmental Performance Index. *© Yale University 2015. All Rights Reserved*. Available at: http://epi.yale.edu/our-methods

[Accessed September 4, 2015].

European Commission - Joint Research Centre & Institute for Environment and Sustainability, 2012. *Characterisation factors of the ILCD Recommended Life Cycle Impact Assessment methods Database and supporting information. First edition.*, Luxembourg: Publications Office of the European Union. Available at: http://lct.jrc.ec.europa.eu/ [Accessed November 4, 2016].

Eurostat - European comission, 2008. Eurostat Manual of Supply, Use and Input-Output Tables. Available at: http://ec.europa.eu/eurostat/documents/3859598/5902113/KS-RA-07-013-EN.PDF/b0b3d71e-3930-4442-94be-70b36cea9b39?version=1.0 [Accessed December 8, 2016].

EXIOBASE Consortium, 2015. About EXIOBASE. Available at: http://exiobase.eu/index.php/about-exiobase [Accessed November 11, 2016].

Fischer-Kowalski, M. et al., 2011. *UNEP (2011) Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel.*, Available at: http://www.unep.org/resourcepanel-old/Portals/24102/PDFs/Decoupling_Factsheet_English.pdf.

Flörke, M. et al., 2013. Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study. Global Environmental Change. , 23(1), pp.144–156.

Giljum, S. et al., 2016a. Identifying priority areas for European resource policies: a MRIO-based material footprint assessment. *Journal of Economic Structures*, 5(1), p.17. Available at: http://journalofeconomicstructures.springeropen.com/articles/10.1186/s40008-016-0048-5 [Accessed October 16, 2016].

Giljum, S. et al., 2016b. Identifying priority areas for European resource policies: a MRIO-based material footprint assessment. *Journal of Economic Structures*, 5(1), p.17. Available at: http://journalofeconomicstructures.springeropen.com/articles/10.1186/s40008-016-0048-5 [Accessed November 13, 2016].

Goedkoop, M. & Spriensma, R., 2001. The Eco-indicator 99 - A damage oriented method for Life Cycle Impact Assessment Methodology Annex.

Grainger, R., 1999. Global trends in fisheries and aquaculture B. Cicin-Sain, R. W. Knecht, & N. Foster, eds. *Trends and future challenges for U.S. national ocean and coastal policy: proceedings of a workshop organized by the National Ocean Service, NOAA, Center for the Study of Marine Policy at the University of Delaware*, pp.21–25. Available at: http://oceanservice.noaa.gov/websites/retiredsites/natdia_pdf/ctrends_proceed.pdf.

Hansen, M.C. et al., 2013. *High-resolution global maps of 21st-century forest cover change*, Available at: http://www.sciencemag.org/lookup/doi/10.1126/science.1244693.

Hastings, C. et al., 1947. Low Moments for Small Samples: A Comparative Study of Order Statistics. *The Annals of Mathematical Statistics*, 18(3), pp.413–426. Available at: http://www.jstor.org/stable/2235737.

Hertwich, E.G., 2011. THE LIFE CYCLE ENVIRONMENTAL IMPACTS OF CONSUMPTION. *Economic Systems Research*, 23(1), pp.27–47.

Hertwich, E.G. & Peters, G.P., 2010. Multiregional Input-Output Database.

Hoekstra, A.Y., Wiedmann, T.O., 2014. Humanity's unsustainable environmental footprint. *Science 344*, pp.1114–1117. Available at: http://www.ayhoekstra.nl/pubs/Hoekstra-Wiedmann-2014-EnvironmentalFootprint.pdf [Accessed August 24, 2015].

Hoekstra, A.Y. & Wiedmann, T.O., 2014. Humanity's unsustainable environmental footprint. *Science (New York, N.Y.)*, 344(6188), pp.1114–7. Available at: http://www.sciencemag.org/content/344/6188/1114.figures-only [Accessed November 4, 2015].

Hsu, A. et al., 2014a. 2014 EPI – Indicator Metadata. Available at: http://epi.yale.edu/files/2014_epi_metadata.pdf.

Hsu, A. et al., 2014b. Indicator, Issue, and Objective Weightings of the 2014 EPI. Available at: http://epi.yale.edu/content/indicator-issue-and-objective-weightings [Accessed October 9, 2015].

Hsu, A. et al., 2014. The 2014 Environmental Performance Index. *New Haven, CT: Yale Center for Environmental Law and Policy*. Available at: http://www.epi.yale.edu [Accessed September 1, 2015].

Hsu, A. et al., 2014c. *The 2014 Environmental Performance Index. Full report and Analysis*, New Haven, CT. Available at: www.epi.yale.edu.

Hsu, A. et al., 2014d. Why Isn't My Country Listed? | Environmental Performance Index. Available at: http://epi.yale.edu/why-isnt-my-country-listed [Accessed September 14, 2015].

Hsu, A. et al. (2016), 2016. *2016 Environmental Performance Index*, New Haven, CT. Available at: www.epi.yale.edu [Accessed November 13, 2016].

Hsu, A., Johnson, L.A. & Lloyd, A., 2013. Measuring Progress: A Practical Guide From the Developers of the Environmental Performance Index (EPI). Available at: http://epi.yale.edu/files/ycelp_measuring_progress_manual.pdf.

Huijbregts, M. et al., 2007. Postgraduate School of Industrial Ecology - Life Cycle Assessment. , pp.30–31.

IEA, 2013. Tracking Clean Energy Progress 2013. Available at: http://www.iea.org/etp/tracking/.

ILO, 2014. ILOSTAT Database.

ILO, 2013. LABORSTA Internet. Available at: http://laborsta.ilo.org/.

International Energy Agency (IEA), 2013. CO2 Emissions form Fuel Combustion, 2013 Edition. Available at: http://data.iea.org/IEASTORE/DEFAULT.ASP [Accessed September 29, 2015].

International Monetary Fund, 2013a. World Economic Outlook Database (GDP PPP). *World Economic Outlook*. Available at: http://www.imf.org/external/pubs/ft/weo/2013/01/weodata/weorept.aspx?pr.x=48&pr.y=6&sy=2002&ey=2011&scsm=1&ssd=1&sort=subject&ds=%2C&br=1&c=528&s=PPP GDP%2CPPPPC&grp=0&a= %0A [Accessed December 20, 2016].

International Monetary Fund, 2013b. World Economic Outlook Databse (GDP PPP per capita). Available at: http://www.imf.org/external/pubs/ft/weo/2013/01/weodata/weorept.aspx?pr.x=48&pr.y=

6&sy=2002&ey=2011&scsm=1&ssd=1&sort=subject&ds=%2C&br=1&c=528&s=PPPGDP%2CPPPPC&grp=0&a= [Accessed December 20, 2016].

Jackson, T., 2009. *Prosperity without growth? The transition to a sustainable economy*, Available at: http://www.sd-commission.org.uk/data/files/publications/prosperity_without_growth_report.pdf.

Johnson, L., 2013. National Status of the Dirty Dozen POPs Regulation through the Stockholm Convention.

Kanemoto, K. et al., 2013. International trade undermines national emission reduction targets: New evidence from air pollution. *Global Environmental Change*, 24, pp.52–59.

Kleisner, K. & Pauly, D., 2011. Stock-catch status plots of fisheries for regional seas. *The State of Biodiversity and Fisheries in Regional Seas.*, 19(3), pp.37–40.

Labuschagne, C., Brent, A.C. & van Erck, R.P.G., 2005. Assessing the sustainability performances of industries. *Journal of Cleaner Production*, 13(4), pp.373–385. Available at: http://www.researchgate.net/publication/222687615_Assessing_the_Sustainability_Performances_of_Industries [Accessed December 5, 2015].

Lenzen, M., Moran, D., et al., 2012. International trade drives biodiversity threats in developing nations. *Nature*, 486(7401), pp.109–12. Available at: http://dx.doi.org/10.1038/nature11145 [Accessed September 7, 2015].

Lenzen, M., Kanemoto, K., et al., 2012. Mapping the Structure of the World Economy. *Environmental Science and Technology*, 46, pp.8374–8381.

Li, L., Willett, T.D. & Zhang, N., 2012. The Effects of the Global Financial Crisis on China's Financial Market and Macroeconomy. *Economics Research International*, 2012, pp.1–6. Available at: http://www.hindawi.com/journals/ecri/2012/961694/ [Accessed January 21, 2017].

Lote, P.A., 2015. India: – Fattige land har rett til å forurense. *Norsk Rikskringkasting (NRK)*. Available at: http://www.nrk.no/urix/indias-statsminister-advarer-rike-land-for-parismote-1.12679170.

Malik, O., 2013. Global database of National Wastewater Treatment.

Mekonnen, M.M. & Hoekstra, A.Y., 2011. *National water footprint accounts: the green, blue and grey water footprint of production and consumption.*, Delft, the Netherlands. Available at: http://www.unesco-ihe.org/Value-of-Water-Research-Report-Series/Research-Papers [Accessed August 14, 2013].

Müller, M., Dominguez, I.P. & Gay, S.H., 2009. Construction of Social Accounting Matrices for the EU-27 with a Disaggregated Agricultural Sector (AgroSAM).

NASA Socioeconomic Data and Applications Center hosted by the Center for International Earth Science Information Network (CIESIN), 2011. Global Rural Urban Mapping Project, v.1. Available at: http://sedac.ciesin.columbia.edu/data/set/grump-v1-population-count [Accessed December 29, 2016].

National Statistics Republic of China (Taiwan), 2016a. 01-01-01 Land, agricultural land and forest land areas (CSV). *Statistical Yearbook of the Republic of China 2015, edited 2016*. Available at:

http://eng.stat.gov.tw/lp.asp?ctNode=6341&CtUnit=1072&BaseDSD=36&mp=5 [Accessed December 12, 2016].

National Statistics Republic of China (Taiwan), 2016b. 02-01-01 General situation of population (CSV). *Statistical yearbook of the republic of China 2015, edited 2016*. Available at: http://eng.stat.gov.tw/lp.asp?CtNode=6339&CtUnit=1072&BaseDSD=36&mp=5 [Accessed December 12, 2016].

OECD, 2014. OECD Statistics. Available at: http://stats.oecd.org/ [Accessed October 12, 2016].

Olson, D.M. et al., 2001. Terrestrial Ecoregions of the World: A New Map of Life on Earth. A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *BioScience*, 51(11), pp.933–938. Available at: http://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world.

Organization for Economic Cooperation and Development Working Group on Environmental Information and Outlook, 2004. OECD Workshop on Material Flows and Related Indicators: Chair's Summary. ENV/EPOC/SE(2004)2. Available at: http://www.oecd.org/env/indicators-modelling-outlooks/32367214.pdf [Accessed December 30, 2016].

Parris, T.M. & Kates, R.W., 2003. CHARACTERIZING AND MEASURING SUSTAINABLE DEVELOPMENT. *Annu. Rev. Environ. Resour.*, 28(1 1), pp.559–586.

Peng, Y. & F&ES'17, 2015. Technology-adjusted Carbon Emissions Accounting | Environmental Performance Index. Available at: http://epi.yale.edu/indicators-in-practice/technology-adjusted-carbon-emissions-accounting [Accessed December 13, 2015].

Peters, G., Briceno, T. & Hertwich, E., 2004. POLLUTION EMBODIED IN NORWEGIAN CONSUMPTION. Available at: https://www.ntnu.no/c/document_library/get_file?uuid=cc092ab4-241d-45b4-9be0-ddef4632f6e0&groupId=10370.

Peters, G.P., 2008. From production-based to consumption-based national emission inventories. *Ecological Economics*, 65(1), pp.13–23.

Peters, G.P. & Hertwich, E.G., 2006. The Importance of Imports for Household Environmental Impacts. *Journal of Industrial Ecology*, 10(3), pp.89–109. Available at: http://doi.wiley.com/10.1162/jiec.2006.10.3.89 [Accessed November 29, 2015].

Peters, G.P. & Hertwich, E.G., 2009. The Application of Multi-regional Input-Output Analysis to Industrial Ecology. In S. Suh, ed. *Handbook of Input-Output Economics in Industrial Ecology*. Dordrecht: Springer Netherlands, pp. 847–863. Available at: http://dx.doi.org/10.1007/978-1-4020-5737-3_38.

Pfister, S. et al., 2011. Environmental impacts of water use in global crop production: hotspots and trade-offs with land use. *Environmental Science & Technology*, 45(13), pp.5761–5768.

Pfister, S. & Bayer, P., 2014. Monthly water stress: spatially and temporally explicit consumptive water footprint of global crop production. *Journal of Cleaner Production*, 73, pp.52–62.

Pulles, T. et al., 2007. Assessment of Global Emissions from Fuel Combustion in the Final Decades of the 20th Century. Application of the Emission Inventory Model TEAM. Available at: http://resolver.tudelft.nl/uuid:66b6a88f-e8f8-4e2c-aadc-ef551190ec9b.

Ricker, W.E., 1975. *Computation and interpretation of biological statistics of fish populations*, Ottawa.

Rosling, H., 2015. The truth about poverty. Available at: https://tv.nrk.no/program/KOID25009915/kapital-hans-rosling-og-sannheten-om-fattigdom.

Schandl, H. et al., 2016. Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions. *Journal of Cleaner Production*, 132, pp.45–56.

Schmidt, J.H. et al., 2012. CREEA report: Recommendation of terminology, classification, framework of waste accounts and MFA, and data collection guideline. Deliverable 4.1 of the EU FP7.

de Sherbinin, A. et al., 2013. Indicators in Practice: How Environmental Indicators are Being Used in Policy and Management Contexts.

Singh, R.K. et al., 2012. An overview of sustainability assessment methodologies. *Ecological Indicators*, 15(1), pp.281–299. Available at: http://www.sciencedirect.com/science/article/pii/S1470160X11000240 [Accessed July 12, 2014].

Skelton, A. et al., 2011. Mapping Flows of Embodied Emissions in the Global Production System. *Environmental Science & Technology*, 45(24), pp.10516–10523. Available at: http://pubs.acs.org/doi/abs/10.1021/es202313e [Accessed January 22, 2017].

Stadler, K. et al., 2017. EXIOBASE 3 Developing a time series of detailed Environmentally Extended Multi-Regional Input-Output tables. *Under review at Journal of Industrial Ecology*.

Steinberger, J.K. & Roberts, J.T., 2010. From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975–2005. *Ecological Economics*, 70(2), pp.425–433.

Telnes, C.M., 2015. *Review of the 2014 Environmental Performance Index*, Trondheim.

The World Bank Group, 2016a. World Bank - GDP, PPP (current international $). Available at: http://databank.worldbank.org/data/reports.aspx?source=2&series=NY.GDP.PCAP.PP.CD&country=# [Accessed December 20, 2016].

The World Bank Group, 2016b. World Bank - GDP per capita, PPP (current international $). Available at: http://databank.worldbank.org/data/reports.aspx?source=2&series=NY.GDP.PCAP.PP.CD&country=# [Accessed December 20, 2016].

The World Bank Group, 2016c. World Bank - Population, total. Available at: http://databank.worldbank.org/data/reports.aspx?source=2&series=SP.POP.TOTL&country= [Accessed November 2, 2016].

The World Bank Group, 2016d. World Bank - Population density. Available at:

http://databank.worldbank.org/data/reports.aspx?source=2&series=EN.POP.DNST&country=# [Accessed December 12, 2016].

Tukker, A. et al., 2016. Environmental and resource footprints in a global context: Europe's structural deficit in resource endowments. *Global Environmental Change*, 40, pp.171–181.

Tukker, A. et al., 2013. EXIOPOL – DEVELOPMENT AND ILLUSTRATIVE ANALYSES OF A DETAILED GLOBAL MR EE SUT/IOT. *Economic Systems Research*, 25(1), pp.50–70. Available at: http://www.tandfonline.com/doi/abs/10.1080/09535314.2012.761952 [Accessed December 7, 2015].

Tukker, A. et al., 2014. The Global Resource Footprint of Nations. Carbon, water, land and materials embodied in trade and final consumption calculated with EXIOBASE 2.1. Available at: http://exiobase.eu/index.php/publications/creea-booklet/73-creea-booklet-web-resolution/file.

Tukker, A. et al., 2009. Towards a global multi-regional environmentally extended input-output database. *Ecological Economics*, 68(7), pp.1928–1937.

Tukker, A. & Dietzenbacher, E., 2013. GLOBAL MULTIREGIONAL INPUT–OUTPUT FRAMEWORKS: AN INTRODUCTION AND OUTLOOK. *Economic Systems Research*, 25(1), pp.1–19.

UN, 2000. United Nations Millennium Declaration, Resolution adopted by the General Assembly. Available at: http://www.un.org/millennium/declaration/ares552e.pdf.

UNDESA, 2013. System of Environmental-Economic Accounting for Energy. SEEA-Energy. Draft Version for Global Consultation.

UNEP-WCMC, 2013. Protected planet. *The World Database on Protected Areas (WDPA) June Release*. Available at: http://www.protectedplanet.net/ [Accessed September 22, 2015].

United Nations, Background UN Millennium Development Goals. Available at: http://www.un.org/millenniumgoals/bkgd.shtml [Accessed November 6, 2015].

United Nations, 2013. World Population Prospects: The 2012 Revision. Available at: http://esa.un.org/wpp/Excel-Data/mortality.htm.

University of British Columbia Fisheries Centre, 2011. Sea Around Us Project. Available at: http://www.seaaroundus.org/.

University of British Columbia Fisheries Centre, 2013. Sea Around Us Project. *Sea Around Us*. Available at: http://www.seaaroundus.org/ [Accessed September 14, 2015].

Usubiaga, A. & Acosta-Fernández, J., 2015. CARBON EMISSION ACCOUNTING IN MRIO MODELS: THE TERRITORY VS. THE RESIDENCE PRINCIPLE. *Economic Systems Research*, 27(4), pp.458–477. Available at: http://dx.doi.org/10.1080/09535314.2015.1049126.

VLIZ Maritime Boundaries Geodatabase VLIZ, 2012. Marine Regions. *Maritime Boundaries Geodatabase version 6*. Available at: http://www.marineregions.org/ [Accessed September 22, 2015].

Walpole, R.E. et al., 2012. *Probability & Statistics for Engineers & Scientists Ninth Edition* 9th ed., Pearson.

Ward, J.D. et al., 2016. Is Decoupling GDP Growth from Environmental Impact Possible? D. E. Naya, ed. *PLOS ONE*, 11(10), p.e0164733. Available at: http://dx.plos.org/10.1371/journal.pone.0164733 [Accessed December 5, 2016].

Weinzettel, J. et al., 2014. Ecological footprint of nations: Comparison of process analysis, and standard and hybrid multiregional input–output analysis. *Ecological Economics*, 101, pp.115–126.

von Weizsäcker, E.U., D. et al., 2014. *UNEP (2014) Decoupling 2: technologies, opportunities and policy options. A Report of the Working Group on Decoupling to the International Resource Panel*, United Nations Environment Programme (UNEP). Available at: http://www.unep.org/resourcepanel-old/Portals/24102/PDFs/IRP DECOUPLING 2_Summary - web.pdf.

Wiedmann, T. et al., 2007. Examining the global environmental impact of regional consumption activities — Part 2: Review of input–output models for the assessment of environmental impacts embodied in trade. *Ecological Economics*, 61(1), pp.15–26.

Wood, R., Stadler, K., Bulavskaya, T., Lutter, S., Giljum, S., de Koning, A., Kuenen, J., Schütz, H., Acosta-Fernández, J., Usubiaga, A., Simas, M., Ivanova, O., Weinzettel, J., Schmidt, J.H., et al., 2015. Global sustainability accounting-developing EXIOBASE for multi-regional footprint analysis. *Sustainability (Switzerland)*, 7(1), pp.138–163.

Wood, R., Stadler, K., Bulavskaya, T., Lutter, S., Giljum, S., de Koning, A., Kuenen, J., Schütz, H., Acosta-Fernández, J., Usubiaga, A., Simas, M., Ivanova, O., Weinzettel, J., Schmidt, J., et al., 2015. Global Sustainability Accounting—Developing EXIOBASE for Multi-Regional Footprint Analysis. *Sustainability*, 7(1), pp.138–163. Available at: http://www.mdpi.com/2071-1050/7/1/138/htm [Accessed December 13, 2015].

Wood, R. et al., 2014. HARMONISING NATIONAL INPUT—OUTPUT TABLES FOR CONSUMPTION-BASED ACCOUNTING — EXPERIENCES FROM EXIOPOL. *Economic Systems Research*, 26(4), pp.387–409. Available at: http://www.tandfonline.com/doi/abs/10.1080/09535314.2014.960913 [Accessed January 3, 2017].

World Bank, 2012. GDP, PPP (current international $) | Data | Table. Available at: http://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD [Accessed September 29, 2015].

World Bank & Sustainable Energy for All Initiative, 2013. Global Tracking Framework. Available at: http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2013/05/28/000112742_20130528084417/Rendered/PDF/778890GTF0full0report.pdf.

World Commission on Environment and Development (WCED), 1987. *Our common future*, Oxford: Oxford University Press.

World Health Organization, 2006. WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global 2005 Update.

World Health Organization & UNICEF, 2013. WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation. Available at: http://www.wssinfo.org/dataestimates/table/.

World Health Organization & UNICEF, 2012. WHO/UNICEF Joint Monitoring Programme

(JMP) for Water Supply and Sanitation. Available at: http://www.wssinfo.org/data-estimates/table/.

World Resources Institute, 2013. Climate Analysis Indicators Tool (CAIT), v.2.0. Available at: http://cait.wri.org/historical/Country GHG Emissions?indicator[]=Total GHG Emissions Excluding Land-Use Change and Forestry&indicator[]=Total GHG Emissions Including Land-Use Change and Forestry&year[]=2012&chartType=geo [Accessed September 29, 2015].

WU, 2015. Global Material Flow Database. 2015 Version. Available at: http://www.materialflows.net [Accessed August 14, 2013].

Wu, X., 2014. What is the EPI? (EPI Methodology Infographic). *2014 EPI*. Available at: http://epi.yale.edu/files/epi_methodology_infographic.pdf [Accessed January 1, 2015].

Zhou, X. & Schoenung, J.M., 2007. An integrated impact assessment and weighting methodology: evaluation of the environmental consequences of computer display technology substitution. *Journal of environmental management*, 83(1), pp.1–24. Available at: http://www.sciencedirect.com/science/article/pii/S0301479706000387 [Accessed December 5, 2015].

APPENDIX

APPENDIX A: RAW DATA DISTRIBUTION

Raw data distribution plots for each EXIOBASE indicator for the year 2011.

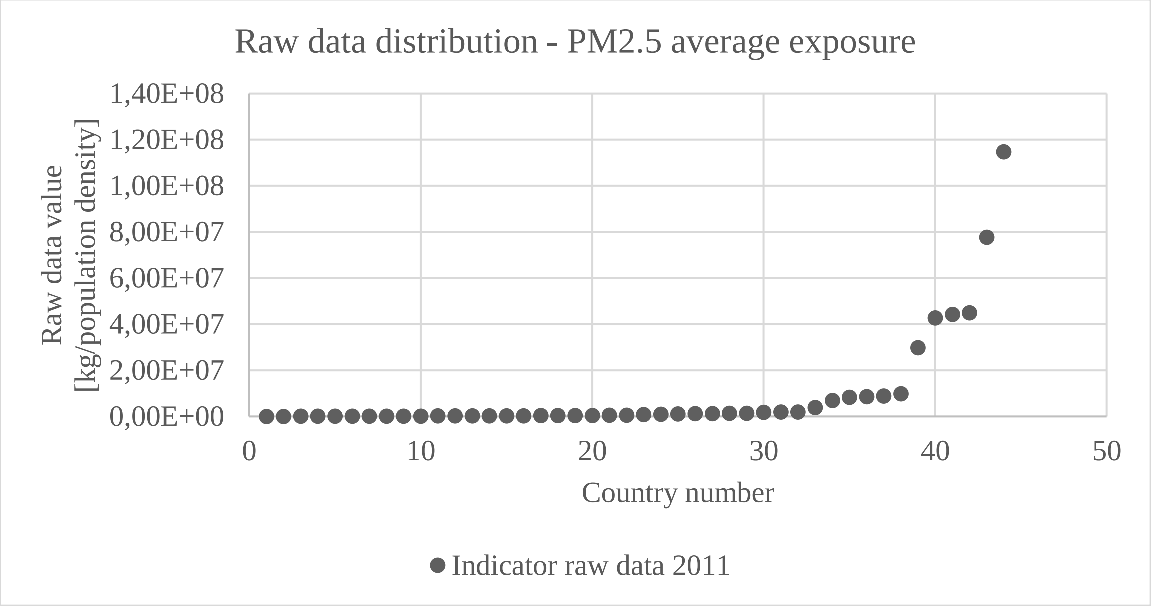


Figure 24: Raw data distribution plot for PM2.5 Average Exposure for the year 2011.

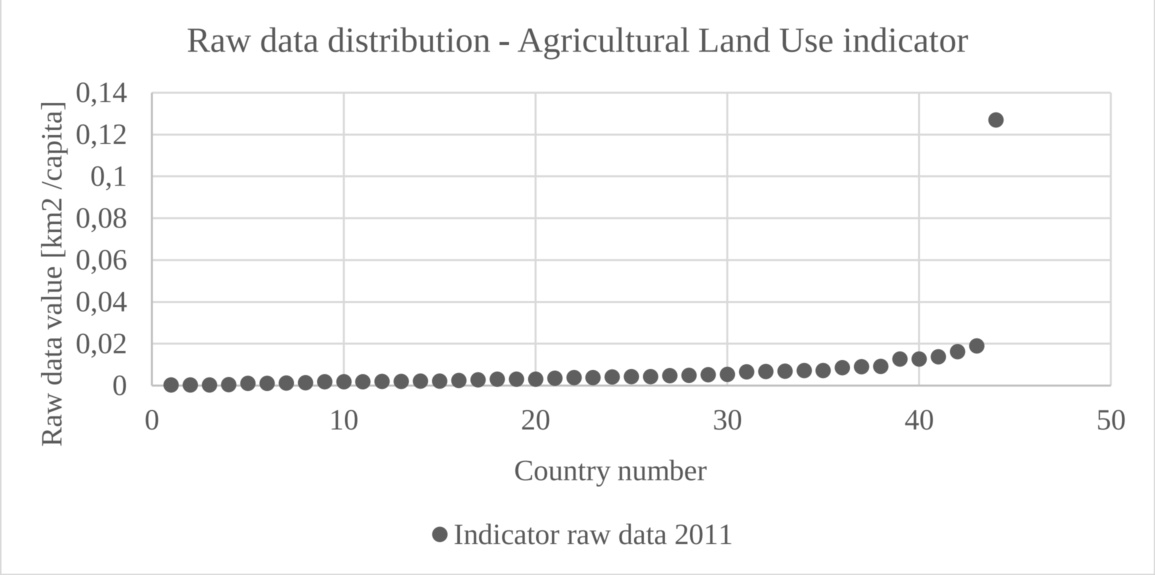


Figure 25: Raw data distribution plot for Agricultural Land Use for the year 2011.

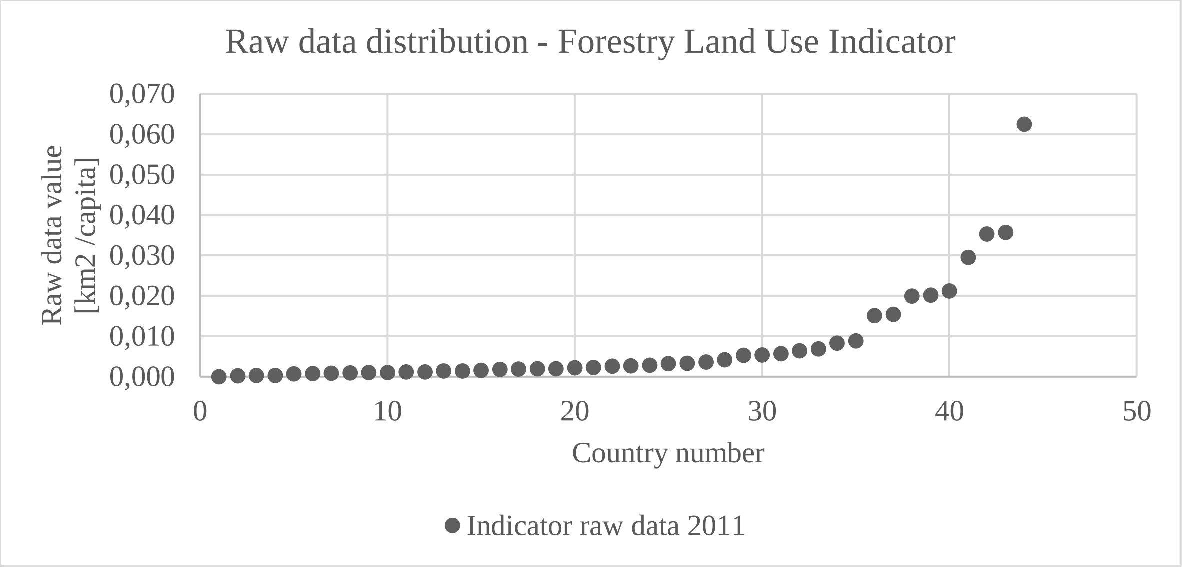


Figure 26: Raw data distribution plot for Forestry Land Use for the year 2011.

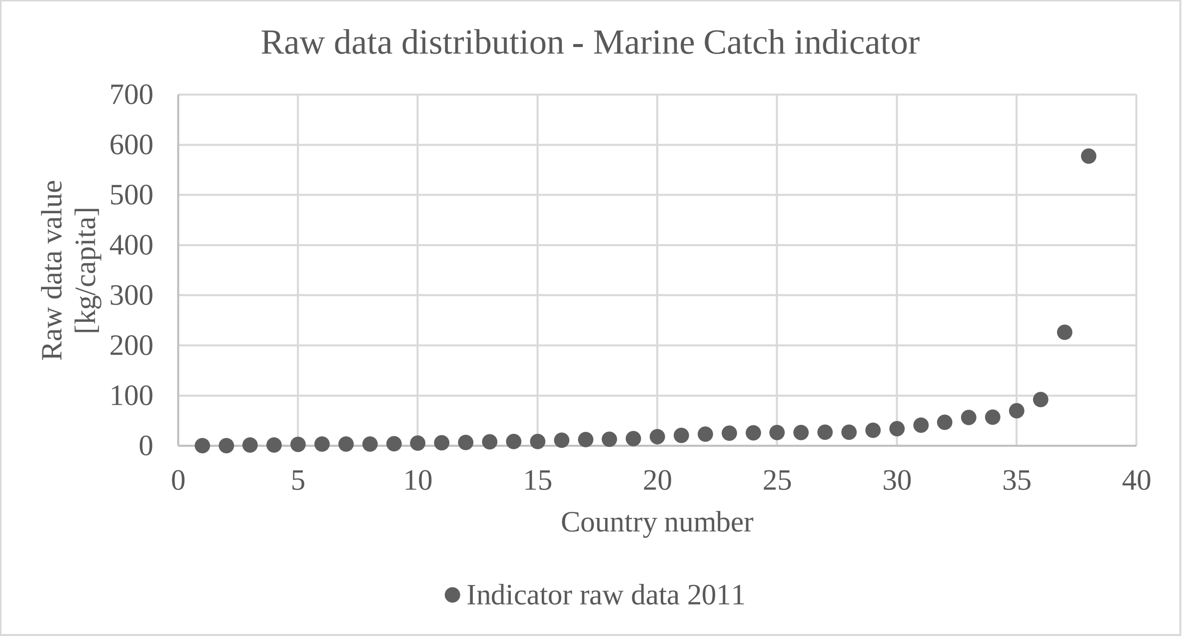


Figure 27: Raw data distribution plot for Marine Catch for the year 2011.

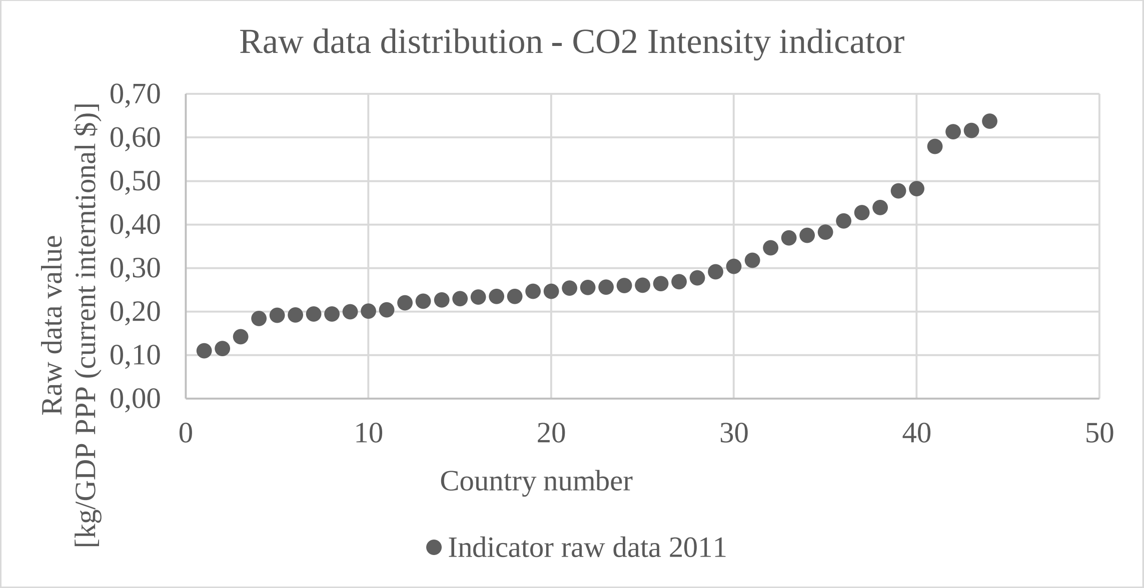


Figure 28: Raw data distribution plot for CO2 Intensity for the year 2011.

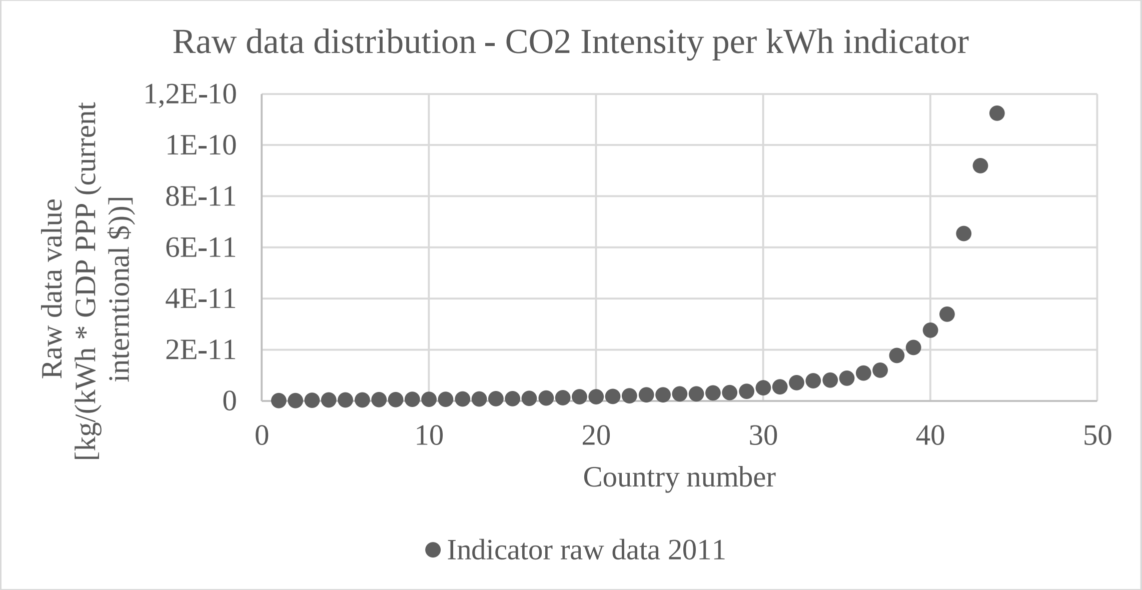
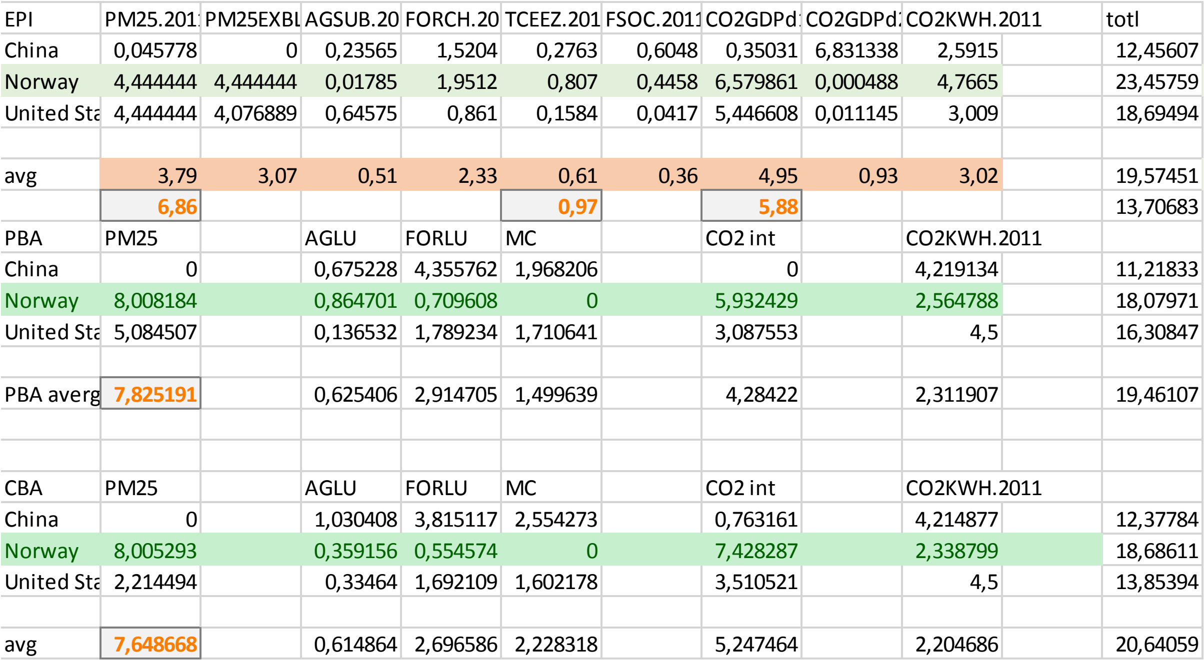


Figure 29: Raw data distribution plot for CO_2 Intensity per kWh for the year 2011.

APPENDIX B: INFLUENCE SCORES

Table 18: Average influence scores per indicator and calculation scheme for China, Norway and the US.



EPI	PM25.201	PM25EXBL	AGSUB.20	FORCH.20	TCEEZ.201	FSOC.2011	CO2GDPd	CO2GDPd	CO2KWH.2011		totl
China	0,045778	0	0,23565	1,5204	0,2763	0,6048	0,35031	6,831338	2,5915		12,45607
Norway	4,444444	4,444444	0,01785	1,9512	0,807	0,4458	6,579861	0,000488	4,7665		23,45759
United Sta	4,444444	4,076889	0,64575	0,861	0,1584	0,0417	5,446608	0,011145	3,009		18,69494
avg	3,79	3,07	0,51	2,33	0,61	0,36	4,95	0,93	3,02		19,57451
	6,86				0,97		5,88				13,70683
PBA	PM25		AGLU	FORLU	MC		CO2 int		CO2KWH.2011		
China	0		0,675228	4,355762	1,968206		0		4,219134		11,21833
Norway	8,008184		0,864701	0,709608	0		5,932429		2,564788		18,07971
United Sta	5,084507		0,136532	1,789234	1,710641		3,087553		4,5		16,30847
PBA averg	7,825191		0,625406	2,914705	1,499639		4,28422		2,311907		19,46107
CBA	PM25		AGLU	FORLU	MC		CO2 int		CO2KWH.2011		
China	0		1,030408	3,815117	2,554273		0,763161		4,214877		12,37784
Norway	8,005293		0,359156	0,554574	0		7,428287		2,338799		18,68611
United Sta	2,214494		0,33464	1,692109	1,602178		3,510521		4,5		13,85394
avg	7,648668		0,614864	2,696586	2,228318		5,247464		2,204686		20,64059

Table 19: Total average influence scores for 2011 by calculation scheme for China, Norway and the US.

Country/calculation scheme	EPI	PBA	CBA
China	12,46	11,22	12,38
Norway	23,46	18,08	18,69
USA	18,69	16,31	13,85

APPENDIX C: MATERIALITY FILTER 2014 EPI

Table 20: Materiality filters of the 2014 Environmental Performance Index (A. Hsu et al. 2014), URL: http://epi.yale.edu/files/filters_materiality_for_2014epi.xls.

Variable	Explanation
Landlock	Country has no coastline.
LDC	Least-developed country; classified based on a set of criteria by the United Nations regarding poverty, human resource weakness, and economic vulnerability.
BadFish	Insufficient or inadequate data reported to evaluate fish stocks; country given lowest average score for the given year for the Fish Stocks and Coastal Fishing Pressure indicators.
BadEEZ	Insufficient or inadequate data for at least one Exclusive Economic Zone (EEZ), which stretch 200 nautical miles outward from a country's coastline and are key tools in effective fisheries management; country given lowest observed value for EEZ.
NoFor	Total forested area is less than 200 square kilometres.
Coast	Ratio of coastline to land area is less than 0.01. If materiality not met, then country not scored on Fisheries.
SIDS	Small Island Developing States; a group of 52 low-lying coastal countries that have small but growing populations, limited resources, and share challenges.
Landarea	Land area in square kilometres.
POP	Population in millions.
GNICAP	Gross National Income (GNI) per capita in $
GNICAP.GROUP	Countries fall into one of three income groups: Low: GNI ≤ $1,035; Middle: $1,036 ≤ GNI ≤ $12,615; High: GNI ≥ $12,616
CLIMATE.FILTER	Countries that receive a "1" were not scored on the Climate and Energy indicator.
GNICAP4	Countries fall into one of four income groups based on their GNIS: Low: GNI ≤ $1,035; Lower-Middle: $1,036 ≤ GNI ≤ $4,084; Higher-Middle: $4,085 ≤ GNI ≤ $12,615; High: GNI ≥ $12,616

APPENDIX D: NORMAL QUANTILE-QUANTILE PLOTS FOR EACH EXIOBASE INDICATORS.

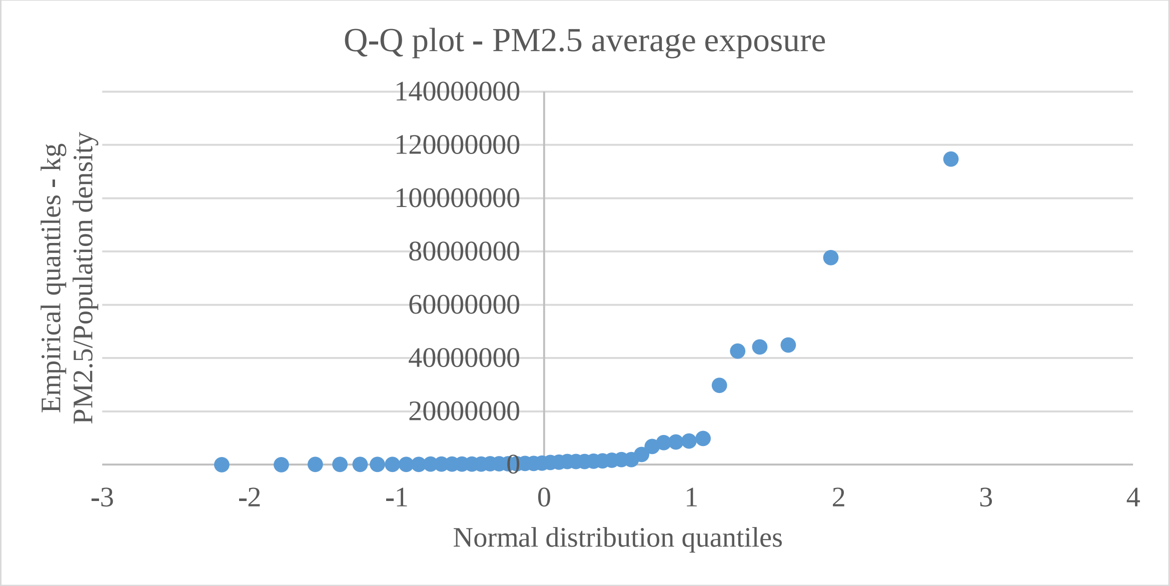


Figure 30: Normal Quantile-Quantile plot PM2.5 Average Exposure for 2011.

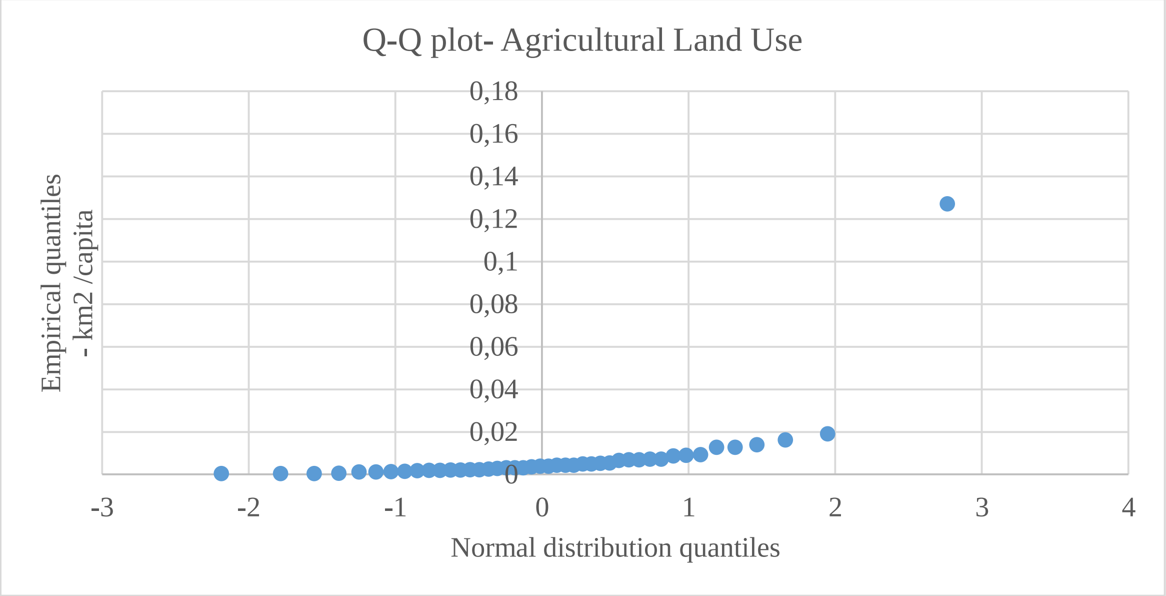


Figure 31: Normal Quantile-Quantile plot Agricultural Land Use for 2011.

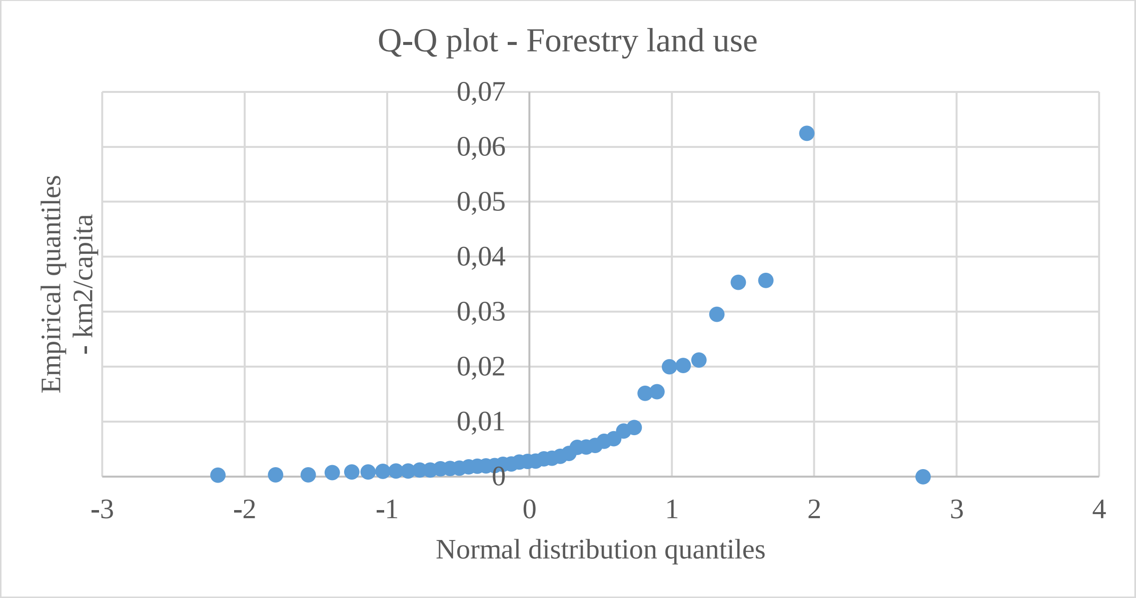


Figure 32: Normal Quantile-Quantile plot Forestry Land Use for 2011.

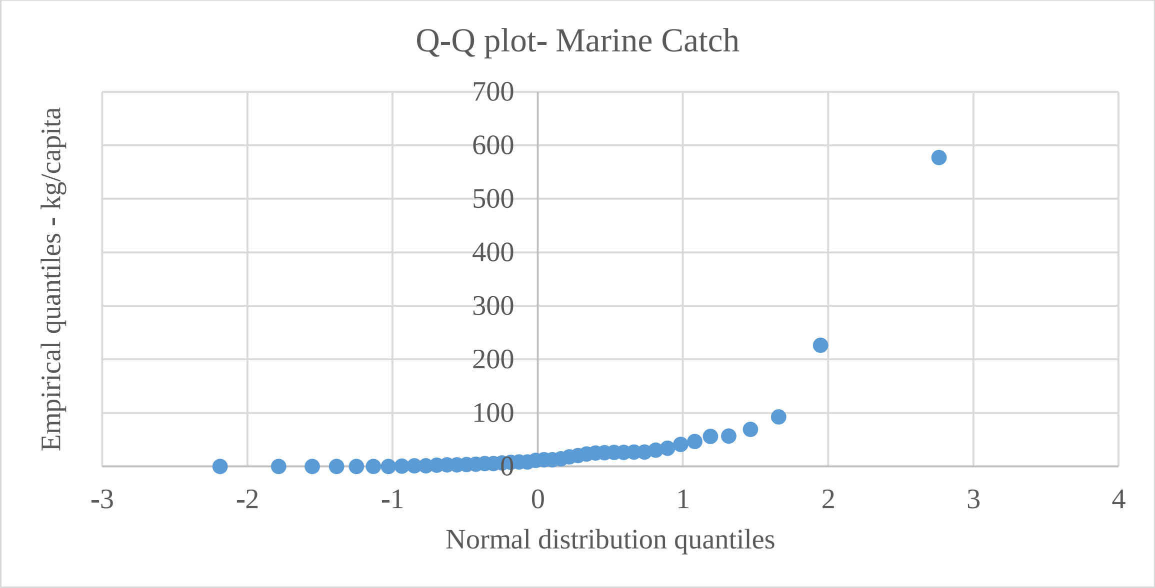


Figure 33: Normal Quantile-Quantile plot Marine Catch for 2011.

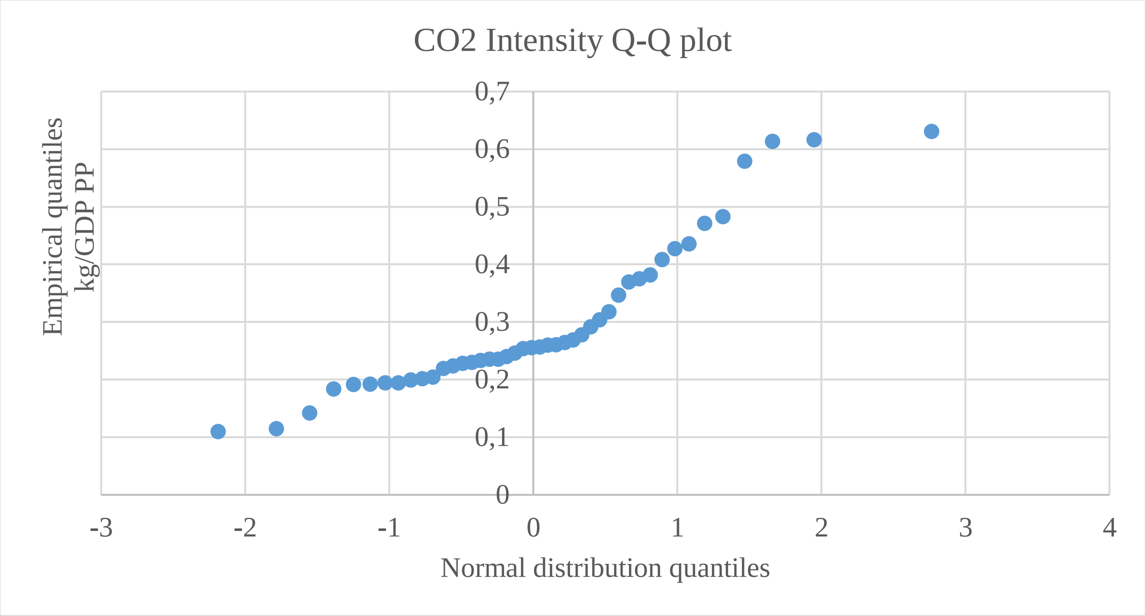


Figure 34: Normal Quantile-Quantile plot CO2 Intensity for 2011.

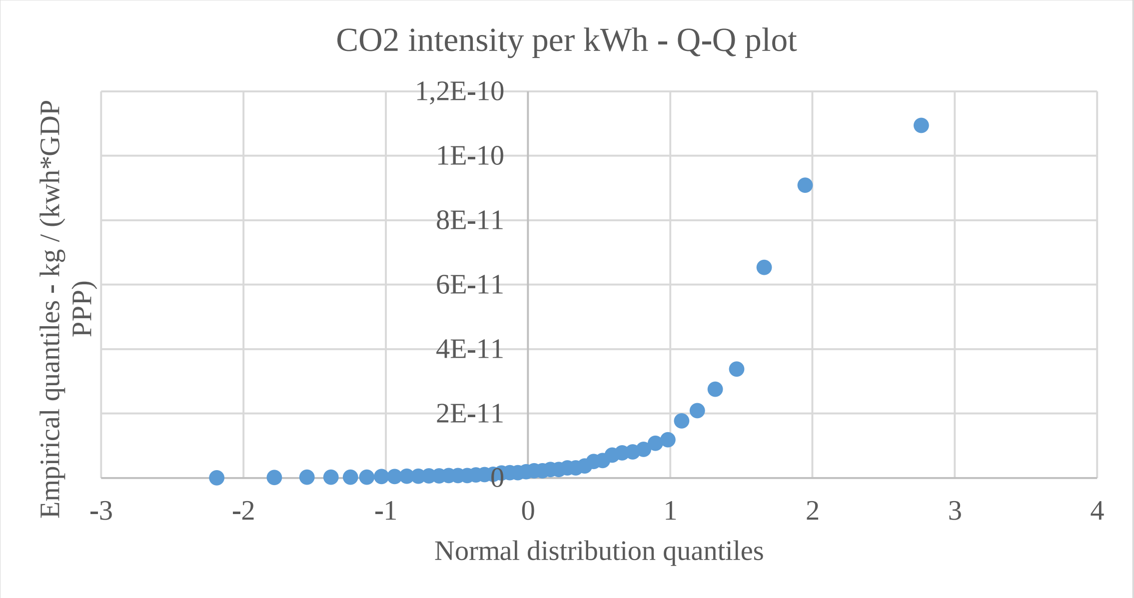


Figure 35: Normal Quantile-Quantile plot CO2 Intensity per kWh for 2011

APPENDIX E: EXIOBASE STRESSOR OVERVIEW

Table 21: EXIOBASE stressors applied to the alternative indicators

Indicator	Stressors
PM2.5 average exposure	PM2.5 - combustion - air|air|kg PM2.5 - non combustion - Agglomeration plant - pellets - air|air|kg PM2.5 - non combustion - Agglomeration plant - sinter - air|air|kg PM2.5 - non combustion - Aluminium ores and concentrates (Bauxite) - air|air|kg PM2.5 - non combustion - Bricks production - air|air|kg PM2.5 - non combustion - Briquettes production - air|air|kg PM2.5 - non combustion - Carbon black production - air|air|kg PM2.5 - non combustion - Cast iron production (grey iron foundries) - air|air|kg PM2.5 - non combustion - Cement production - air|air|kg PM2.5 - non combustion - Chemical wood pulp, dissolving grades - air|air|kg PM2.5 - non combustion - Chemical wood pulp, soda and sulphate, other than dissolving grades - air|air|kg PM2.5 - non combustion - Chromium ores and concentrates - air|air|kg PM2.5 - non combustion - Copper ores and concentrates - air|air|kg PM2.5 - non combustion - Fertilizer production (N-fertilizer) - air|air|kg PM2.5 - non combustion - Glass production - air|air|kg PM2.5 - non combustion - Gold ores and concentrates - air|air|kg PM2.5 - non combustion - Iron ores and concentrates - air|air|kg PM2.5 - non combustion - Lead ores and concentrates - air|air|kg PM2.5 - non combustion - Lime production - air|air|kg PM2.5 - non combustion - Mining of antracite - air|air|kg PM2.5 - non combustion - Mining of bituminous coal - air|air|kg PM2.5 - non combustion - Mining of coking coal - air|air|kg

Table 22: EXIOBASE stressors applied to the alternative indicators.

Indicator	Stressors
PM2.5 average exposure	PM2.5 - non combustion - Mining of lignite (brown coal) - air|air|kg PM2.5 - non combustion - Mining of sub-bituminous coal - air|air|kg PM2.5 - non combustion - Molybdenum ores and concentrates - air|air|kg PM2.5 - non combustion - N- fertilizer production - air|air|kg PM2.5 - non combustion - Nickel ores and concentrates - air|air|kg PM2.5 - non combustion - Nickel, unwrought - air|air|kg PM2.5 - non combustion - Oil refinery - air|air|kg PM2.5 - non combustion - Pig iron production, blast furnace - air|air|kg PM2.5 - non combustion - Platinum ores and concentrates - air|air|kg PM2.5 - non combustion - Primary aluminium production - air|air|kg PM2.5 - non combustion - Production of coke oven coke - air|air|kg PM2.5 - non combustion - Production of gascoke - air|air|kg PM2.5 - non combustion - Refined copper; unwrought, not alloyed - air|air|kg PM2.5 - non combustion - Refined lead, unwrought - air|air|kg PM2.5 - non combustion - Secondary aluminium production - air|air|kg PM2.5 - non combustion - Semi-chemical wood pulp, pulp of fibers other than wood - air|air|kg PM2.5 - non combustion - Silver ores and concentrates - air|air|kg PM2.5 - non combustion - Steel production: basic oxygen furnace - air|air|kg PM2.5 - non combustion - Steel production: electric arc furnace - air|air|kg PM2.5 - non combustion - Steel production: open hearth furnace - air|air|kg PM2.5 - non combustion - Tin ores and concentrates - air|air|kg PM2.5 - non combustion - Unrefined copper; copper anodes for electrolytic refining - air|air|kg PM2.5 - non combustion - Zinc ores and concentrates - air|air|kg PM2.5 - non combustion - Zinc, unwrought, not alloyed - air|air|kg

Table 23: EXIOBASE stressors applied to the alternative indicators.

Indicator	Stressor
Agricultural Land Use	Land use - Arable Land - Rice|nature|km2 Land use - Arable Land - Wheat|nature|km2 Land use - Arable Land - Other cereals|nature|km2 Land use - Arable Land - Vegetables, fruits, nuts|nature|km2 Land use - Arable Land - Oil crops|nature|km2 Land use - Arable Land - Sugar crops|nature|km2 Land use - Arable Land - Fibres|nature|km2 Land use - Arable Land - Other crops|nature|km2 Land use - Arable Land - Fodder crops|nature|km2 Land use - Permanent pasture|nature|km2
Forestry Land Use	Used Forest Land - Industrial roundwood|nature|km2 Used Forest Land - Wood fuel|nature|km2
Marine Catch	Domestic Extraction Used - Fishery - Marine fish catch|kt| Domestic Extraction Used - Fishery - Other (e.g. Aquatic mammals)|kt| Unused Domestic Extraction - Fishery - Marine fish catch|kt| Unused Domestic Extraction - Fishery - Other (e.g. Aquatic mammals)|kt|
CO2 intensity	CO2 - combustion - air|air|kg CO2 - non combustion - Cement production - air|air|kg
CO2 intensity per kWh	Energy Carrier Use Electricity by Geothermal|TJ| Energy Carrier Use Electricity by biomass and waste|TJ| Energy Carrier Use Electricity by coal|TJ| Energy Carrier Use Electricity by gas|TJ| Energy Carrier Use Electricity by hydro|TJ| Energy Carrier Use Electricity by nuclear|TJ| Energy Carrier Use Electricity by petroleum and other oil derivatives|TJ| Energy Carrier Use Electricity by solar photovoltaic|TJ| Energy Carrier Use Electricity by solar thermal|TJ| Energy Carrier Use Electricity by tide, wave, ocean|TJ| Energy Carrier Use Electricity by wind|TJ| Energy Carrier Use Electricity nec|TJ|

APPENDIX F: EPI INDICATOR OVERVIEW

Detailed results of EPI indicator recalculation and methodology evaluation.

Data extracted from “2014 EPI – indicator metadata” (A Hsu et al. 2014a).

Table 24: Overview of the 2014 EPI metadata used in the indicator recalculations.

2014 EPI indicators	Logarithmic transformation (alpha value)	Need for inversion	Target (High Performance Benchmark)	Low Performance Benchmark	Unit
Child Mortality	Yes (0,00048524)	No	0,00075676	0,137	Probability
Air Pollution avg. Exp. PM2.5	Yes (0,03)	No	10	49,92	µg/m^3
Air Pollution PM2.5 exceedance	No	No	0	69,5	% of population
Household Air Quality	No	No	0	1	% of population
Access to Drinking Water	Yes (1)	Yes	1	36,21	% of population
Access to Sanitation	Yes (1)	Yes	1	0	% of population
Wastewater Treatment	No	No	1	14,09	% of treated wastewater
Critical Habitat Protection	No	No	1	0	% of protected sites
Terrestrial Protected Areas (National Biome Weights)	No	No	17	0	% of area protected
Terrestrial Protected Areas (Global Biome Weights)	No	No	17	0	% of area protected
Marine Protected Areas	Yes (0,000255309)	No	10	0	% of EEZ under protection
Agricultural Subsidies	Yes (0,0005669)	No	0	0,856	% border price
Pesticide Regulation	No	No	25	0	points
Change In Forest Cover	Yes (0,1)	No	0	7,75	% change in forest cover
Fish Stocks	No	No	0	0,2	Fraction of overexploitation
Coastal Shelf Fishing Pressure	Yes (0,00000147)	No	0,0000161	1,86	kt/km^2
Trend in Carbon Intensity	Yes (n/a)	No	-0,0781	0,014	Trend (kg CO2/GDP PPP)
Change of Trend in Carbon Intensity	Yes (n/a)	No	-0,122	0,06	Change in trend (kg CO_2 /GDP PPP)
Trend in CO_2 Emissions per kWh	Yes (n/a)	No	-0,06	0,068	Trend (kg CO_2/kWh)
Access To Electricity	Not used for EPI calculation				

Child Mortality

The data preparation for this indicator serves as an example for the PBA indicators not deemed relevant for the further parts of this thesis. It represents a case where the raw data is not readily reproducible from the data source.

Data preparation

The indicator measures the probability of child mortality between the ages of one to five years old (4q0). The raw data is derived using the infant mortality rate (1q0) and under-five mortality (5q0) medium variants from the United Nations *World Population Prospects: The 2012 Revision* (United Nations 2013). These data are applied to the formula provided in the *Metadata* to calculate the probability of child mortality between the child's first and fifth birthday. However, the report introduced above does not explicitly state that the mortality values are the medium variant. Since the archive of the United Nations webpage is unavailable at this time (21. Sept 2016), I am unable to retrieve the necessary data sets to check this. When calculating a few samples to check the formula, the obtained values are close to the ones found in the raw data file, but not exactly. E.g. for Afghanistan, the mortality rate is 92,3 and 67,3 for 5q0 and 1q0 respectively for 2010-2015. Imputed in the formula, the result is 0,026803903 which is close to 0,027439327 the 2012 raw data. Since the data is for a time period of five year, an interpolation has probably been used to refine the value. This is also mentioned in the methodology description in the "*2014 EPI – Indicator metadata*" document (A Hsu et al. 2014a).

Data transformation

A logarithmic transformation was used, and the alpha value of 0,00048524 was applied prior to transformation. Exactly how, and to which values it was applied is not clearly described in the methodology, but by adding the alpha value to the 2012 raw data values, as well as to the target and low performance benchmark when calculating, it yields a result that is very close to the 2014 EPI score.

Data conversion to indicators

Target: 0,00075676 probability

LPB: 0,137 probability

As explained above, the alpha value is added to the 2012 raw data, as well as to the target and the (LPB) before transforming the data logarithmically. Then the range is calculated by taking the logarithm of the adjusted LPB and target, and then subtracting the former from the latter. Then Equation (1) is applied using ln (LPB + alpha) – ln (Target + alpha) as the range, ln (Target + alpha) as the new target and ln (raw data + alpha) for the actual value.

The deviation between the 2014 EPI score and the calculated score is up to 5,24 EPI score points, with and average deviation of 0,22 points. The scores that should receive 100 (raw data smaller than the target) need to be picked out manually, because the formula only yields scores ranging from 94,7 to 99,85 for these countries.

Household Air quality

Data preparation

The raw data is taken directly from Table S2 found in the data source specified in the Metadata available at https://ehp.niehs.nih.gov/wp-content/uploads/121/7/ehp.1205987.s001.pdf.

Data transformation

No transformation needed.

Data conversion to indicators

Target: 0 %

LPB: 100 %

The range is 100% - 0 % = 100 %, the target is zero and the actual value is the raw data for 2010. By applying these values to the Equation (1), the exact 2014 EPI indicator score is obtained.

Air Pollution PM2.5 Exceedance

Data preparation

See *Air Pollution - Average Exposure to PM2.5*

Data transformation

No transformation needed.

Data conversion to indicators

Target: 0 %

LPB: 69,5 % (0,695 raw data value)

The PM2.5 exceedance score is calculated by first taking the arithmetic mean of the 2012 raw data values for each of the four exceedance categories (10, 15, 30, 35 µg/m^3). The arithmetic mean for each country is then applied to Equation (1) using the range of 0,695 - 0 = 0,695 following the *Metadata* methodology description. This yields the exact EPI score for all countries except Bangladesh, China, Nepal and Pakistan, which all get negative values. This is due to their raw data percentages being higher than the LPB, and their 2014 EPI score is set to zero.

Air Pollution - Average Exposure to PM2.5

Data preparation

"Average exposure is calculated by multiplying the PM2.5 concentration by the population exposed. It reflects a 'typical' air pollution day a person would experience in a country" (A. Hsu et al. 2014). However, there is not enough detail in the description specifying which of the values from the population grid http://sedac.ciesin.columbia.edu/data/set/grump-v1-

population-count/data-download were used, and recreation of the raw data was thus unsuccessful.

Data transformation

Logarithmically transformed with the application of an alpha value of 0,03 before transformation.

Data conversion to indicators

Target: 10 µg/m^3.

LPB: 49,92 µg/m^3 (maximum value of the entire data set from 2000-2012).

First, the countries with documented air pollution levels below the target are given a score of 100 manually, as this result is not obtained through application of Equation (1). The alpha value is added to the 2012 raw data as well as to the target and LPB. The logarithmic transformation yields the new range of ln (49,92 + 0,03) - ln (10 + 0,03), the new target ln (10 + 0,03) and the new actual value of ln (raw data + 0,03). Inserting these values into Equation (1) yields the exact 2014 EPI scores when rounded.

Wastewater Treatment

Data preparation

Data preparation for this indicator was not investigated further based on previous deductions.

Data transformation

No transformation needed.

Data conversion to indicators

Target: 100 %

LPB: 14,09 %

For this indicator the raw data only contains data for the year 2012. When rounding up and comparing these values to the 2014 EPI indicator score they match up exactly rendering the calculation step redundant. This does on the other hand represent an inconsistency in the indicator calculation methodology that is used for the other indicators. Following the same logic as for the others, the range would be calculated to be 100 % - 14,09 %. This, however, does not yield the correct result. Additionally, all values below the LPB are usually set to zero, but not in this case.

Access to Drinking Water

Data preparation

Data is taken from WHO/ UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation, but the source is no longer available thus making it impossible to verify the calculation method.

Data transformation

Inversion and logarithmic transformation with added alpha value of 1.

Data conversion to indicators

Target: 100 %

LPB: 36,21 %

The raw data shows the percentage of the population with access to drinking water. However, inverting the data set portrays the percentage of the population without access to drinking water instead. This means that the range and target need to be inverted as well. The alpha value equals 1 for this indicator. Thus the inverted range becomes (100% - 36,21 %) + 1 = 64, 79 % when the alpha value is added. The same goes for the target that now becomes 0% + 1 =1 % instead of 100%, and the raw data which changes to (100% - raw data %) + 1.

Logarithmically transforming these values and putting them into Equation (1) yields the exact 2014 EPI indicator scores except for the following countries: Comoros, Dominica, Equatorial Guinea, Eritrea, Grenada, Libya, Lithuania, Paraguay, Romania and Venezuela. The *Metadata* does not give an explanation for the values imputed for the aforementioned countries, although they are all listed with missing values in the raw data file.

Access to Sanitation

Data preparation

Data is taken from WHO/ UNICEF Joint Monitoring Programme (JMP) for Water Supply And Sanitation, but the source is no longer available thus making it impossible to verify the calculation method.

Data transformation

Inversion and logarithmic transformation with added alpha value of 1.

Data conversion to indicators

Target: 100 %

LPB: 0 %

The same inversion and logarithmic transformation as for *Access to Drinking Water* is seemingly applied for this indicator. However, adding the alpha value of 1 to the inverted range means that it becomes ln (101) while the target becomes ln (1). The actual value is obtained through inversion of the 2011 raw data values by subtracting each value from 100, and then adding the alpha value to the result of the inversion. Since the two indicators in the *Water and Sanitation* issue category have the same methodology for score calculation, the method should work. However, in this case the calculated scores are not exactly the same as the 2014 EPI indicator scores. The largest deviation is for Benin with 3,25 score points more than the 2014 EPI score. The mean deviation is 1,589 EPI score points for all 178 countries. Generally, the calculated score is higher than the 2014 EPI indicator score.

Agricultural Subsidies

Data preparation

This indicator is based on using monetary data on agricultural subsidies. Countries are scored based on their income level, which is specified in the *Materiality Filter*. Negative subsidies were set to zero. Countries with agricultural GDP below 5% were not scored. Countries with lower and middle income countries i.e. Gross National income (GNI)/ capita below $4085, were imputed with a zero value. High income countries (GNI above $12616 PPP) values were imputed based on regional GDP model if agricultural GDP is above 5% of total GDP of a country (A Hsu et al. 2014a).

Since the data used in the EXIOBASE indicator is not related to the units or data used by the EPI, the data preparation will not be further investigated.

Data transformation

Logarithmic transformation with an alpha value of 0,0005669 applied prior to transformation.

Data conversion to indicators

Target: 0 %

LPB: 0,856%

The raw data for 2011 mostly features not available inputs, however the remaining values can be applied to Equation (1) to calculate the exact 2014 EPI indicator score. The range is ln (0,856 + alpha value) – ln (alpha value), the target is ln (alpha value) and the actual value equals the logarithmic transformation of the raw data added to the alpha value.

For the NA entries, the *Materiality Filter* categorizing countries by income (GNI) must be consulted to determine each country's score. The data preparation described above explains the scoring methodology which is based on the GNICAP4 category in the materiality filter provided on the EPI download webpage http://epi.yale.edu/downloads under "*Archive: 2014 EPI materials*". It divides countries into four groups; low-income, lower middle, higher middle and high income. The criteria set by the EPI developers decide which countries should not be scored, and which should get a raw data value of zero value, the latter yielding an indicator score of 100.

Unfortunately, the *Metadata* description is flawed due to the higher-middle income class (GNI/capita between $4085 and $12616) not being mentioned with any specific scoring methodology. This leaves many countries in the raw data with no specified score attribution. In addition, many of the low and lower-middle income countries are given scores differing from the score the *Metadata* suggests they should be given, i.e. a 2014 EPI indicator score of 100. This is true for Benin, Chad, Egypt, India, Indonesia, Morocco, Mozambique, the Philippines, Tanzania, Senegal, Ukraine, Vietnam and Zambia.

Pesticide Regulation

Data preparation

Data preparation for this indicator was not investigated further based on previous deductions.

Data transformation

No transformation needed.

Data conversion to indicators

Target: 25 points

LPB: 0 points

Equation (1) is applied with both range and target set to 25 points, and with the raw data from 2012. This yields the exact 2014 EPI indicator scores.

Change in forest cover

Data preparation

Countries that had less than 200 sq.km. Of >50% tree cover in the year 2000 were not given a score. This only affects Malta among the EXIOBSE countries (A Hsu et al. 2014a). The data was extracted from Table S3 (not S2 as stated in the *Metadata*) in the supplementary material of the data source cited in the *Metadata* available at http://science.sciencemag.org/content/sci/suppl/2013/11/14/342.6160.850.DC1/Hansen.SM.pdf. The metadata explains that the "net change in forest cover was calculated by subtracting column *p* (total gain / year 2000 > 50% tree cover) from column *n* (> 50% tree cover loss / year 2000 > 50% tree cover)."(A Hsu et al. 2014a). The absolute values were reproducible, however if the description is to be directly follow, it would imply subtracting as I shown below, but the raw data show the same values, only of opposite sign.

Examples:

USA calculated: Column *n* of 9,7 – column *p* 5,6 = 4,1. USA raw data: -4,1.

China calculated: Column *n* of 4,2 – column *p*1,7 = 2,5. China raw data: -2,5.

Norway calculated: Column n of 3,6 – column *p* 1,8 = 1,8. Norway raw data: -1,8.

Data transformation

Logarithmic transformation with an alpha value of 0,1 applied prior to transformation.

Data conversion to indicators

Target: 0 %

LPB: 7,75 %

The 2014 EPI indicator score was calculated using a range of ln (7,75 + alpha value) – ln (alpha value) and a target of ln (0,1). The actual values were calculated by adding the alpha value to the absolute value of the 2012 raw data. Then Equation (1) was applied using the aforementioned values. This yields a calculated score very close to the EPI score, where the largest deviation is at 0,02 points lower than the 2014 EPI score. Some scores end up being negative, thus below the target of 0 %. These are adjusted to an EPI indicator score of zero.

For the following countries the calculated score deviates far from the EPI score (e.g. up to 71,86 in the case of Mauritius), with no apparent explanation given in the *Metadata*: Australia, Bosnia and Herzegovina, Chile, Cuba, Hungary, Mauritius, Moldova, Montenegro, Morocco, New Zealand, Serbia, South Africa and Tunisia. These countries are all given an indicator score of 100 in the 2014 EPI, but this is not reflected in the calculations.

Fish stocks

Data preparation

The data preparation of this indicator was not attempted due to its elaborate methodology, and low relevance for the proposition and calculation of the alternative EXIOBASE indicator.

Data transformation

No transformation needed.

Data conversion to indicators

Target: 0 %

LPB: 0,2 %

The range was set to 0,2 and the target was set to zero. The 2011 raw data were applied directly together with the range and target in Equation (1), which yields the exact 2014 EPI indicator score. Calculated scores with negative values were adjusted to a final EPI indicator score of zero. This indicator is subject to the *BadFish* materiality filter, which means that countries with inadequate catch data were penalized and given the average lowest score for the two *Fisheries* indicators.

Costal shelf fishing pressure

Data preparation

This indicator uses the area of EEZs as a denominator for its measurement. This data has to be extracted manually for each country form the seaaroundus.org web page, which is both time consuming and irrelevant for the proposed EXIOBASE indicator. Further investigation into the data preparation was thus not conducted.

Data transformation

Logarithmic transformation with an alpha value of 1,47E-06 applied prior to transformation.

Data conversion to indicators

Target: 0,0000161 (tons per km^2)

LPB: 1,86 (tons per km^2)

Using Equation (1) with the logarithmic transforms of the range, target and 2006 raw data values with the alpha value added does not yield the 2014 EPI scores. This is the only indicator that does not yield a good approximation of the EPI scores when reproduced. The only scores that do add up relatively well are the country scores affected by the materiality filter *BadEEZ*, which applies the lowest raw data values over the entire period for the country, instead of using the 2006 values. *"(...) We used the lowest Costal shelf fishing pressure indicator value for a given year out of all the countries to calculate an EEZ weighted-average national aggregation* (A Hsu et al. 2014a).

Critical habitat protection

Data preparation

Data preparation for this indicator was not investigated further based on previous deductions.

Data transformation

No transformation needed.

Data conversion to indicators

Target: 100 %

LPB: 0%

Applying Equation (1) using the raw data from 2012, and setting both range and target equal to 100% yields the exact 2014 EPI indicator scores, although in this case, the nature of the formula makes its use redundant since it returns the same values as the raw data values.

Terrestrial Protected Areas (National biome weights)

Data preparation

Data preparation for this indicator was not investigated further based on previous deductions.

Data transformation

No transformation needed.

Data conversion to indicators

Target: 17 %

Low performance: 0 %

Equation (1) is applied to the latest available raw data year. Both the range and the target is set equal to 17 % which yields the exact 2014 EPI indicator score.

Terrestrial Protected Areas (Global biome weights)

Data preparation

Data preparation for this indicator was not investigated further based on previous deductions.

Data transformation

No transformation needed.

Data conversion to indicators

See Terrestrial Protected Areas (National biome weights).

Marine Protected Areas

Data preparation

Data preparation for this indicator was not investigated further based on previous deductions.

Data transformation

Logarithmic transformation with an alpha value of 0,000255309 applied prior to transformation.

Data conversion to indicators

Target: 10 %

LPB: 0 %

The range applied to the Equation (1) is ln (10 + alpha value) – ln (alpha value). The target used is ln (10 + alpha value), and the actual value is calculated by adding the alpha value to the raw data from 2012 and logarithmically transforming it. However, this method does not yield the exact 2014 EPI indicator score, and the difference between the calculated score and the EPI score is up to 81 points (Haiti). The mean deviation from the 2014 EPI indicator score is 5,33 points across the 178 countries. Most countries have calculated scores close to the 2014 EPI indicator score, but 40 countries have deviations larger than 2 points, which is a considerable amount, compared to the other indicators considered in this section. Since this indicator is not considered relevant for the following work, these deviations will not be investigated further.

Trend in Carbon Intensity

Data preparation

The data source listen in the Metadata links directly to the source web page (http://cait2.wri.org/historical/Country%20GHG%20Emissions?indicator[]=Total%20GHG%20Emissions%20Excluding%20Land-Use%20Change%20and%20Forestry&indicator[]=Total%20GHG%20Emissions%20Including%20Land-Use%20Change%20and%20Forestry&year[]=2012&sortIdx=NaN&chartType=geo) which directs to data on GHG-emissions. However, the data stated to be used in both the raw data set and the metadata is kg CO2. The web page also contains data of Total CO2 emissions excluding land use change and forestry. Moreover, the metadata says GDP PPP (current international $) were use, and the link directs to the same data type, while the raw data sheet says that year 2000 constant US dollars were used. Already, there are discrepancies between the method and the data sources, and GDP PPP in constant US dollars for 2000 is no longer available at the Word Bank data bank website. Attempts to recalculate the raw data using GDP PPP (current international $) did not yield the correct values.

Data transformation

Logarithmic transformation.

Data conversion to indicators

Target: -0.0781 (trend)

LPB: 0,0014 (trend)

Taking the natural logarithm of the values from 2000 to 2010 found in the "CO2 per GDP" tab in the excel sheet "*climate_and_energy.xls*" (available at the EPI downloads webpage in the"*2014 EPI Raw Data Files*" folder) and using the SLOPE-function in Excel yields the linear regression slope of the data points. This method almost perfectly matches the slope given in the EPI raw data, but since the *Metadata* does not state what kind of regression is used, an exact replication cannot be conducted.

However, applying the calculated slope to Equation (1), with the target and LPB given in the *Metadata* resulting in a range of 0,0795, and multiplying by 0,9 (as done by the EPI) yields scores close to the 2014 EPI. Any values outside the range are given either a zero score for values higher than the LPB, and a 90 score for countries with values lower than the target. Although this technique works for most countries, some scores are set to "not available" by the EPI, even though there are available raw data values. The reason for this is not mentioned or explained in the *Metadata.* Some data needs extrapolation, but it does not affect the EXIOBASE selection, so it will not be further investigated here.

Change of Trend in Carbon Intensity

Data preparation

See Trend in Carbon Intensity

Data transformation

Log transformation.

Data conversion to indicators

Target: -0.122

LPB: 0,06

Here, the slope was calculated in a similar fashion as in the *Trend in Carbon Intensity* indicator (using the same tab in the Excel sheet and a logarithmic transformation), only here there are two slopes, one for 2001-2005 and one for 2006-2010. The resulting slopes for these two periods where subtracted from each other (the latter minus the first) to yield the change in trend. Using this trend to calculate the score by applying Equation (1) multiplied by 0,9 with the range of 0,182 (calculated from subtracting the target from the LPB). The resulting scores are very close to the 2014 EPI, however there are small deviations for all countries but most lie within 0,4 in absolute score value.

Trend in CO_2-emissions per kWh

Data preparation

Data source only available through purchase, thus not attempted recreated.

Data transformation

Logarithmic transformation

Data conversion to indicators

Target: -0,06

LPB: 0,068

Although not clearly specified, the logarithmic transformation in this case is done on the values in the *CO2 per KWH* tab in the same excel sheet as for the two other indicators of the *Climate and Energy* issue category: "*climate_and_energy.xls*". According to the *Metadata*, a regression is used between the year 2000 and 2010 which then gives the slope, i.e. the trend, in CO2-emissions per kWh. A simple linear slope calculation (Excel SLOPE function) shows values close to the ones found in the trend raw data in the *CO2 per KWH* tab, which the indicator score calculation is based on.

In contrast to the two preceding indicators of this issue category, the score calculation does not yield a good fit for the 2014 EPI. The indicator is stated to have been constructed using both the slope trends for some countries, while for the top performers the score is supposedly based on the absolute value of *CO2 per KWH*. Attempting to use this value and alternatively the logarithmic transformation of this value does not yield the final EPI score (example of Norway which gets a score of 95,33, while the score calculation yields a score of -1391 (well off the charts compared to the other scores and should result in a score of 90 using the log value of the CO2/kwh, and a score of 76 using the calculated slope). In other words, this indicator is not reproducible. An additional problem here is that some of the final indicator scores exceed the 90 point range. By using Equation (1) with a target of -0,06, a range of 0,068 – (0,06) = 0,128 to the raw data trend, and multiplying by 0,9 as instructed in the *Metadata*, the calculation does not yield the exact 2014 EPI indicator scores, and while some countries (e.g. China and Australia) have scores close to the original value, others are further off (e.g. Greece and Finland).

Access to electricity

Not used for EPI final score, therefore not considered.

APPENDIX G: EMAIL CORRESPONDENCE WITH DR. ANGEL HSU

Date: 05.10.2016

Dear Ms. Hsu.

I'm currently writing my master thesis at the Norwegian University of Science and Technology (NTNU), and in this context I permit myself to contact you regarding some questions I have concerning the methodology of the Environmental Performance Index 2014. My study includes a closer look at the EPI 2014 framework, as well as the index construction, indicator calculations, and weighting scheme. Through this work, I have come across some issues that I was hoping you could help me resolve.

So far, I have attempted to recreate the calculated scores of the EPI 2014 by following the methodology description given in the metadata file, the full report and in the "Measuring Progress: A Practical Guide From the Developers of the Environmental Performance Index (EPI)" (Hsu, A., L.A. Johnson, and A. Lloyd (2013)). However, I have four issues with respect to this.

1st issue:

Based on the raw data provided in the download section of the EPI website, I am unable to get the exact EPI 2014 indicator scores for the following indicators: Child mortality, Access to sanitation, Marine protected areas, Change in forest cover and Coastal shelf fishing pressure. If you could provide me with a more detailed description of the approach used for these calculations I would be most grateful!

2nd issue:

The indicators in the Climate and Energy issue category have both positive and negative raw data values. How did you conduct the logarithmic transformation to get the indicator scores of Trend in carbon intensity, Change of Trend in carbon intensity and Trend in CO2-emissions per kWh?

3rd issue:

What method was used to determine the GDP - adjusted weights for Trend in Carbon Intensity and Change of Trend in Carbon Intensity?

4th issue:

Is there a more detailed description available for how the raw data was calculated than what is already stated in the metadata? For example, the Air pollution 2.5 average exposure and Air pollution 2.5 exceedance raw data combines two different data sets, but I would be very interested to know the exact calculation method.

I hope you can help me, and I look forward to hearing from you!

Respectfully,

Christina Telnes

06/10/2016 from Angel Hsu

Hi Christina,

Can I ask why you want to replicate the 2014 EPI?

Please see below:

1. Did you read the 2014 EPI Metadata document (http://epi.yale.edu/downloads/2014-epi-metadata)? Some indicators have transformations (log, inverse, etc.) applied to them before they are calculated.

2. we calculated the trend in CO2 per Unit GDP from 2000-2010, then took the log.

3. This was complicated. Basically the weighted mean for the CO2GDPd1 and CO2GDPd2 depends on a country's GNI per capita - the wealthier a country is the greater weight CO2GDPd1 receives. LDCs get a pass. The threshold is mentioned in the metadata. We improved on this method a lot for 2016 EPI.

4. Please see these papers for more details about how the PM2.5 data was derived (also in metadata)

[1] van Donkelaar et al. 2010. Global estimates of ambient fine particulate matter concentrations from satellite-based aerosol optical depth: Development and application. Environmental Health Perspectives. 118(6): 847-855.

[2] van Donkelaar et al. 2013. Optimal estimation for global ground-level fine particulate matter concentrations. Journal of Geophysical Research. 118(11): 5621-36.

[3] Boys, B.L., Martin, R.V., van Donkelaar, A., MacDonell, R., Hsu, N.C., Cooper, M.J., Yantosca,R.M., Lu, Z., Streets,D.G., Zhang,Q., Wang,S., Fifteen-year global time series of satellite-derived fine particulate matter, Environ. Sci. Technol, 10.1021/es502113p, 2014.

Angel Hsu

From Christina Telnes 06/10/2016

Hi Angel,

Thanks for getting back to me so soon.

I'm looking at the EPI in connection with an investigation into a consumption based index.

1: yes, I did, but as explained I am not getting the exact results by following the metadata. Therefore it would be helpful to look at a calculation example to figure out where I went wrong in my interpretation.

2: Ok, so the raw data is already logarithmically transformed? Because if not, I cannot see how you took the log of the negative values. Or did you change the scale somehow?

Thank you for the other clarifications!

Best,

Christina Telnes

07/10/2016 from <angel.hsu@yale.edu>

hi Christina,

The EPI is not a consumption-based index. I recommend you look into the Footprint Network's work (Arjen hoekstra), or Wiedmann's material footprint index - those both include consumption methods. I am really very busy and am sorry cannot help you further. Perhaps my researcher Kai Xu (cc-ed) has more time next week and can speak with you on the phone).

1. Please follow the metadata exactly - did you add the alpha value to the raw CHMORT value before you log-transformed? See page 2 of the Metadata:

Logarithmic (alpha value of 0.00048524 added before transformation applied)

Note you need to use natural logs.

2. No - the log transformation happens on CO2GDP BEFORE the slopes are calculated - so the values are all positive. There are no CO2GDPs that are negative.

APPENDIX H: SUMMARY OF THE 2014 EPI INDICATORS – METHODS AND DATA

Extraction from (Telnes 2015).

The following section contains a summary of the EPI's qualitative framework listing each environmental account. The environmental indicators are presented under the corresponding issue category which in turn is categorized under the corresponding policy objective. It is meant to shortly describe what is measured, the rationale for inclusion and how the data was obtained. Data source limitations are stated when applicable. For a more detailed description of the data development method, the reader is referred to http://epi.yale.edu/files/2014_epi_metadata.pdf. The data were gathered via http://epi.yale.edu/our-methods, an thus indirectly the 2014 EPI report (A Hsu et al. 2014c) (since the website is a recap of the full report) and the 2014 EPI – Indicator Metadata collection (A Hsu et al. 2014a).

Ecosystem Vitality

Issue Category: Water Resources

WASTEWATER TREATMENT

What It Measures and Why It Is Included

The indicator measures the percentage of collected wastewater from households and industry that is treated before it is released back into ecosystems. Wastewater contains contaminants like nutrients and chemicals that are harmful to both human and ecosystem health. This indicator is mainly a measure of urban treatment systems due to the lack of sewage system connections in rural areas. Wastewater treatment ensures clean water available for re-use and is especially relevant for areas facing more constrained water resources in the future due to climate change and rapid population growth (A Hsu et al. 2014a).

Data Source Origin, Development and Limitations

The dataset is developed by Yale Center for Environmental Law & Policy (YCELP) using environmental statistics from national ministries, Organization for Economic Cooperation and Development (OECD), United Nations Statistical Division (UNSD) and the Food and Agricultural Organization (FAO) official statistics, Pinsent Masons Water Yearbook and additional expert advice. There is a lack of comparable data across countries because figures on total wastewater generation are unavailable for most countries. Only the wastewater that receives "at least primary treatment" (basic processes such as removal of suspended solids and reduction of the biochemical oxygen demand) are considered because it's the only common definition available for globally comparable measurement due to restricted data availability and gaps (A. Hsu et al. 2014).

This issue category is wrongfully categorized under the Environmental Health objective in the table on page 1 in the Indicator Metadata sheet, see (A Hsu et al. 2014a).

Issue Category: Agriculture

Assesses two policies related to the effects of intensive farming. Both indicators are proxy measures, and for this reason receive relatively lower weighted than other indicators and issues (see chapter 3.4 Weighting of environmental accounts).

AGRICULTURAL SUBSIDIES

What It Measures and Why It Is Included

This indicator is “a proxy measure for the degree of environmental pressure exerted by subsidizing agricultural inputs” (A. Hsu et al. 2014). According to an OECD report, the public subsidies for agricultural protection and agrochemical inputs exerts additional pressure on the environment through intensification of chemical use, farmland expansion into sensitive areas and overexploitation of water and soil nutrients (A Hsu et al. 2014c).

It was discovered that the cited source for this argument (Organization for Economic Cooperation and Development Working Group on Environmental Information and Outlook 2004) available at http://www.oecd.org/env/indicators-modelling-outlooks/32367214.pdf actually does not contain the cited passage found in the metadata and the full EPI 2014 report. The original document is not available through the OECD website, which makes it impossible to double check the reference.

Data Source Origin, Development and Limitations

The indicator uses data from the World Bank database of Nominal Rate of Assistance, defined as “the percentage by which government policies have raised gross returns to farmers above what they would be without the government’s intervention.” (Anderson 2009). The indicator is not capable of differentiating between subsidies that encourage sustainable practices (A. Hsu et al. 2014).

PESTICIDE REGULATION

What It Measures and Why It Is Included

This is a proxy related to policy intent, and assesses the status of countries’ legislation regarding the use of chemicals listed under the Stockholm Convention on Persistent Organic Pollutants (POPs). It also scores countries on how much they have followed through on limiting or outlawing these chemicals (A. Hsu et al. 2014). Due to their toxic nature, pesticides also kill beneficial insects and fauna, as well as having harmful effects on human health. The POPs are known endocrine disruptors, or carcinogens (A Hsu et al. 2014a).

Data Source Origin, Development and Limitations:

Countries are scored based on their efforts toward banning the 'dirty dozen' POPs in the Stockholm Convention (A Hsu et al. 2014a).

Issue Category: Forests

CHANGE IN FOREST COVER

What It Measures and Why It Is Included

The measurement is defined as "percent change in forest cover between 2000 and 2012 in areas with greater than 50 percent tree cover". It includes the factors: deforestation, reforestation (restoration) and afforestation (conversion from non-forest covered land into forest). Reduction in forest cover negatively affects ecosystem services and habitat protection such as climate regulation. It also reduces possibilities of carbon storage, water supplies and biodiversity richness (A Hsu et al. 2014a).

Data Source Origin, Development and Limitations:

A collaboration between the University of Maryland and Google Earth (using Google Earth Engine's Landsat 7 images) resulted in a new high-resolution map of forest loss and gain (A. Hsu et al. 2014). If a country had less than 200 sq. km. of >50% tree cover in 2000, it was not scored in this category (A Hsu et al. 2014a).

Issue Category: Fisheries

This issue category assesses fishing practices in terms of heavy equipment uses and catch size (A. Hsu et al. 2014).

COSTAL SHELF FISHING PRESSURE

What It Measures and Why It Is Included

The indicator measures the total catch from certain fishing methods (trawling and dredging) per total area of the national exclusive economic zones (EEZs). The type of method and equipment used to harvest aquatic species have a large impact on the ocean ecosystems, and are potentially harmful in their own right regardless of the volume of fish caught (e.g. bottom trawling). This indicator reflects overall fishery health by unveiling cases of unsustainable harvest rates or use of practices harmful to the coastal shelf ecosystem. The level of fishing pressure within each coastal country's EEZ is revealed (A Hsu et al. 2014a).

Data Source Origin, Development and Limitations

See Fish Stocks indicator

FISH STOCKS

What It Measures and Why It Is Included

The indicator measures the share of overexploited and collapsed fish stocks within a country's EEZ. That is, the percentage of total catch that consists of overexploited or collapsed species (A Hsu et al. 2014a). Overfishing is harmful to marine life and occurs when fisheries are exploited at levels exceeding their replacement capacity through reproduction and growth of the exploited species (Grainger 1999; Ricker 1975). Fish stocks are listed as undeveloped, developing, fully exploited, overfished, collapsed and recovering (A Hsu et al. 2014a; A. Hsu et al. 2014).

Data Source Origin, Development and Limitations: Valid For Both Fisheries Indicators

The "Sea Around Us Project" compiled and analysed the data. They base their information on data from the FAO, the International Council for the Exploration of the Seas (ICES), the STATLANT database, the Northwest Atlantic Fisheries Organization (NAFO), and data provided from Canada, the United States, and other governments. The 2014 EPI is sensitive to incomplete or inconsistent reporting, deliberate underreporting, and poor monitoring of fisheries, which is a common global trend. 57 countries are penalized for this by scoring them with the lowest observed indicator scores for both Fisheries indicators (A. Hsu et al. 2014).

Issue Category: Biodiversity and Habitat

TERRESTRIAL PROTECTED AREAS (NATIONAL BIOME WEIGHT)

What It Measures and Why It Is Included

The indicator assessment is defined as "the protection of biomes weighted by the proportion of a country's territory the biome occupies." It measures how well the target of protecting 17% of each terrestrial biome within a country's borders is achieved. This target is weighted by the domestic contribution of each terrestrial biome. For an ecological region to be "effectively conserved" the EPI treats protected status as a necessary yet insufficient condition (A Hsu et al. 2014a). Biodiversity and ecosystem services are critical to sustain human life (A. Hsu et al. 2014).

Data Source Origin, Development and Limitations

All indicators in this issue category apply data from the World Database on Protected Areas (WDPA) maintained by the United Nations Environment Programme (UNEP) World Conservation Monitoring Centre. Both Terrestrial Protected Areas indicators apply data from the World Wildlife Fund Ecoregions of the World and the WDPA (A. Hsu et al. 2014). The cap of 17% stems from the Convention on Biological Diversity (CBD) and was set to prevent uneven protection of biomes. "The final indicator is a weighted average of the percentage of land area protected in each biome, with weights derived from the proportion of the national territory falling in each biome." (A Hsu et al. 2014a)

TERRESTRIAL PROTECTED AREAS (GLOBAL BIOME WEIGHTS)

What It Measures and Why It Is Included

The indicator "reflects the protection of biomes weighted by their globally proportional abundance"(A Hsu et al. 2014a). The measure is based on the same principles as the Terrestrial Protected Areas (National Biome Weight), except here the target of protecting 17% of each terrestrial biome within a country's borders is weighted by the global contribution of each terrestrial biome instead (A Hsu et al. 2014a). The reason for inclusion is also the same as for the national biome weight indicator.

Data Source Origin, Development and Limitations

See Terrestrial Protected Areas (National Biome Weight).

MARINE PROTECTED AREAS

What It Measures and Why It Is Included

The indicator is a percentage measure of the protected share of a country's EEZ. Protecting marine areas ensure species diversity and safe havens for endangered species. They also ensure livelihoods for local fisheries as well as commercial ones through the protection of commercial fish stocks (A Hsu et al. 2014a).

Data Source Origin, Development and Limitations

The time series on protected area coverage is developed by the Center for International Earth Science Information Network (CIESIN) based on data from the World Conversation Monitoring Centre's World Database on Protected Areas (A Hsu et al. 2014a). The indicator is built with data from the Flanders Marine Institute (VLIZ) Maritime Boundaries Database and the WDPA. The measurement stems from the targets set by the CBD which established protection goals of 10 percent of marine and coastal areas (A. Hsu et al. 2014).

CRITICAL HABITAT PROTECTION

What It Measures and Why It Is Included

The measurement is defined as "percentage of sites identified by the Alliance for Zero Extinction (AZE) that have partial or complete protection". More than 500 sites representing the last refuge of one or more of the world's most highly threatened species have been identified by the AZE. Protecting these areas for the purpose of biodiversity conservation is of utmost importance (A Hsu et al. 2014a).

Data Source Origin, Development and Limitations

The time series was developed by CIESIN from 2010 to 2011 of protected area coverage based on the date of establishment field in the World Conservation Monitoring Centre's (WCMC) (WDPA)(A Hsu et al. 2014a).

Issue Category: Climate and Energy

This issue category contains four indicators, although it is only presented through one indicator tab on the website http://epi.yale.edu/our-methods/climate-and-energy. This is inconsistent with the general structure used in the other issue categories of the website.

TREND IN CO_2 EMISSIONS PER KWH

What It Measures and Why It Is Included

The indicator measures the "trend in CO_2 emissions per kilowatt hour (kWh) of electricity produced" (A Hsu et al. 2014a). For most countries the trend is determined from 2000 to 2010. For performers at the lowest levels of carbon intensity per kWh of electricity produced, the calculated score is an absolute level of CO_2 emissions per kWh of electricity and heat produced, divided by the total amount of electricity and heat production. The electricity and heat production is used as a measure because the power sector is the largest contributor to CO_2 emissions in most countries (A Hsu et al. 2014a).

Data Source Origin, Development and Limitations

The electricity and heat generation covers thermal power plants, including conventional electricity plants and combined heat and power, nuclear, hydro (excluding pumped storage production), waste, geothermal, and all other renewables. The emission intensity measure should be used with caution due to data quality problems relating to electricity efficiencies for some countries (A Hsu et al. 2014a).

CHANGE OF TREND IN CARBON INTENSITY

What It Measures and Why It Is Included

The indicator measures "countries' abilities to reduce the rate of carbon intensity from 2000-2005 and 2006-2010" (A Hsu et al. 2014a). CO_2 per unit GDP is a common metric assessing the intensity in the output of carbon dioxide emissions. These emissions contribute to climate change. Climate change is a serious environmental challenge, yet mitigation is still lacking and action is needed to prevent further damage. Consensus on the problem's scope, origins, or potential solutions must be reached. This is not a proximity-to-target performance indicator due to the absence of internationally-agreed upon targets. Instead it is a "relative measure of how well countries are reducing the rate of carbon intensity growth over roughly the last decade (2000 to 2010) relative to each other." (A Hsu et al. 2014a; A. Hsu et al. 2014). Counties are also treated differently based on their gross national income (GNI) per capita.

Data Source Origin, Development and Limitations

The CO_2 emission data comes from WRI CAIT's database compiled from several sources: Carbon Dioxide Information Analysis Center, International Energy Agency (IEA), Energy Information Agency, FAO, and the U.S. Environmental Protection Agency (A Hsu et al. 2014a).

TREND IN CARBON INTENSITY

What It Measures and Why It Is Included

The indicator measure "countries' abilities to reduce the intensity of carbon emissions per unit GDP from 2000 to 2010" (A Hsu et al. 2014a). See Change of Trend in Carbon Intensity for additional information.

Data Source Origin, Development and Limitations

See Change of Trend in Carbon Intensity.

ACCESS TO ELECTRICITY

What It Measures and Why It Is Included

The indicator is a measure of the percentage of a population with access to electricity. Although not included in the EPI calculations, the indicator is displayed in relation to goals set by the United Nations (UN) to help transition people in nations like the least developed countries

(LDC’s) to more sustainable energy use (A Hsu et al. 2014a). However, the indicator is not mentioned on the website.

Data Source Origin, Development and Limitations

This indicator is only displayed for reference to the calculation of Climate and Energy for LDC’s and is not included in the calculation of the EPI. Datasets from the World Bank's Global Electrification Database and the WHO Global Household energy Database are used. Data was gathered through surveys and censuses. Modelling was used to fill in missing data points (A Hsu et al. 2014a).

Environmental Health

Issue Category: Health Impacts

CHILD MORTALITY

What It Measures and Why It Is Included

The indicator measures “the probability of a child dying between his or her first and fifth birthdays” (A Hsu et al. 2014a). It is a useful proxy for the human health effects caused by pollution and poor sanitation which are major causes of death in this population group. Infant mortality is not covered, as other factors (e.g. neonatal care, infrastructure and health care) are deemed more important or the survival of this group. Reducing child mortality is the fourth Millennium Development Goal (A Hsu et al. 2014a; A. Hsu et al. 2014).

Data Source Origin, Development and Limitations

Depending on the country, the data which is derived from country statistics, migration reports, and censuses, may vary. Deficiencies are filled using estimates (A Hsu et al. 2014a).

Issue Category: Air quality

HOUSEHOLD AIR QUALITY

What It Measures and Why It Is Included

The indicator measures “the percentage of the population burning solid fuel (biomass such as wood, crop residues, dung, charcoal and coal) for cooking” (A Hsu et al. 2014a). It is a proxy measure assessing indoor solid fuel use, rather than the direct inhalation of particles. Solid fuel use in households is associated with increased mortality from acute lower respiratory diseases among children (e.g. pneumonia) and chronic obstructive pulmonary disease and lung cancer among adults. Low-income households in developing countries are most affected and it is likely larger than indicated by the data due to typically larger families (A Hsu et al. 2014a; A. Hsu et al. 2014).

Data Source Origin, Development and Limitations

The data are taken from the World Health Organization's Household Energy Database, created using household surveys, with a total of 586 data points in 155 countries. Models were used to generate the remaining data points for predicted solid fuel use (A. Hsu et al. 2014). The data are estimates for primary cooking fuel use only, and does not cover fuels such as kerosene. Fuel used for space heating, although sometimes difficult to differentiate (e.g. China), is not covered (A Hsu et al. 2014a).

AIR POLLUTION - AVERAGE EXPOSURE TO PM2.5

What It Measures and Why It Is Included

The indicator measures exposure to PM2.5 in micrograms per cubic meter (µg/m^3) using a population-weighting. It was calculated using a population grid and estimates of annual global surface concentrations. Suspended particulates contribute to acute lower respiratory infections and cancer. Due to their small size, they lodge themselves deep in the lung tissue (A Hsu et al. 2014a; World Health Organization 2006).

Data Source Origin, Development and Limitations

The PM2.5 data were derived using satellite data provided by Aaron van Donkelaar of Dalhousie University. The data for population weighting were obtained from the Global Rural Urban Mapping Project, v.1 at the NASA Socioeconomic Data and Applications Center hosted by the (CIESIN) at Columbia University (A. Hsu et al. 2014). Satellite data were also obtained using Aerosol Optical Depth from NASA’s MODIS, SeaWiFS, and MISR satellite instruments, and the GEOS-Chem chemical transport model. (A Hsu et al. 2014a).

Data source: The PM2.5 data were derived using satellite data provided by Aaron van Donkelaar of Dalhousie University. The data for population weighting were obtained from the Global Rural Urban Mapping Project, v.1 at the NASA Socioeconomic Data and Applications Center hosted by the (CIESIN) at Columbia University (A. Hsu et al. 2014). Satellite data were also obtained using Aerosol Optical Depth from NASA’s MODIS, SeaWiFS, and MISR satellite instruments, and the GEOS-Chem chemical transport model. (A Hsu et al. 2014a)(van Donkelaar et al. 2015; NASA Socioeconomic Data and Applications Center hosted by the Center for International Earth Science Information Network (CIESIN) 2011; Center for International Earth Science Information Network - CIESIN et al. 2011)

AIR POLLUTION - PM2.5 EXCEEDANCE

What It Measures and Why It Is Included

The indicator measures the “average percentage of the population exposed to PM2.5 levels at 10, 15, 25, and 35 micrograms per cubic meter (µg/m^3)”. The three latter are interim health targets set by the WHO. Rationale for inclusion is the same as for Air Pollution - Average Exposure to PM2.5.

Data source origin, development and limitations

See Air Pollution – Average Exposure to PM2.5.

Issue Category: Water and Sanitation

ACCESS TO SANITATION

What It Measures and Why It Is Included

The indicator measures is defined as “the percentage of the population that has access to an improved source of sanitation”. To be considered “improved” a systems must fulfil certain criteria (e.g. be connected to a public sewer or septic system). It must hygienically separate human excreta from human contact and at the same time not be public (i.e. it can either be private or shared). Adequate sanitation maintains the supply of healthy drinking water and minimizes bacterial and viral contact, as well as environmental threats associated with improper waste management (A Hsu et al. 2014a).

Data Source Origin, Development and Limitations

The data was developed by 2012 WHO / United Nations International Children’s Emergency Fund (UNICEF) Joint Monitoring Programme for Water Supply and Sanitation (JMP) (A. Hsu et al. 2014). Results are computed based on number of improved sanitation-users relative to the total population. The estimates were derived from national surveys conducted every 3-4 years (A Hsu et al. 2014a).

ACCESS TO DRINKING WATER

What It Measures and Why It Is Included

The indicator measures the proportion of a country's total population with access to an improved drinking water source (i.e. a facility or delivery point that protects water from external contamination - particularly faecal contamination) as a main source of drinking water. This indicator is the best currently available proxy for this issue. Access to reliable, safe water promotes health by reducing the exposure to pollution, disease (e.g. diarrhea), and harmful contaminants (A Hsu et al. 2014a).

Data Source Origin, Development and Limitations

See Access to Sanitation.

There is a mistake in the metadata sheet under Indicator Creation “Method/Description” where they state “The indicator is computed as the number of people using improved sanitation facilities in relation to the total population, expressed as a percentage” (A Hsu et al. 2014a). However, this is the same as what is stated for Access to Sanitation, and should not be stated in Access to Drinking Water.

Table 25: Quantitative overview of the 2014 EPI Ecosystem Vitality objective. All data are extracted from 2014 EPI – Indicator Metadata, unless otherwise stated (A Hsu et al. 2014a). The metadata sheet contains detailed descriptions of methods of both indicator and data source development. URL: http://epi.yale.edu/files/2014_epi_metadata.pdf

2014 EPI Objective: Ecosystem Vitality **Data source and metadata overview**						
Issue Category	**Indicator**	**Data Source(s) and Type**	**Coverage**	**Date Data Obtained**	**Proxies and Data Specificities**	**TNA**
Water Resources	*Wastewater Treatment*	(Malik 2013) **Type:** Tabular	2012 (averaged from 1995-2012, see methods for notes)	October 20, 2013	Calc. average used if data unavailable. Country specific data.	n/a
Agriculture	*Agricultural Subsidies*	(Anderson & Nelgen 2013) **Type:** Tabular	1955-2011	September 1, 2013	Proxy measure County specific data.[1]	Log
	Pesticide Regulation	(Johnson 2013) **Type:** Tabular	1960-2013	November 4, 2013	County specific data	n/a
Forests	*Change In Forest Cover*	(Hansen et al. 2013) **Type:** Tabular/PDF	2000-2012	November 15, 2013	-	Log
Fisheries	*Costal Shelf Fishing Pressure*	(University of British Columbia Fisheries Centre 2011) **Type:** Tabular	1950-2006	August 31, 2011	-	Log
	Fish Stocks	(University of British Columbia Fisheries Centre 2013) **Type:** Tabular	1950-2011	September 20, 2011	Small island state aggregation. Ad hoc method using current FAO data. Methods to determine stock status vary for years 2007-2011	n/a
		(Kleisner & Pauly 2011) On the Sea Around Us Stock Status Plots.	Footnoted as reference in the indicator data source section of the metadata sheet (A Hsu et al. 2014a)	-	-	-

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[1] Taiwan data are provided by Taiwan's Ministry of Environment

Table 26: Quantitative overview of the 2014 EPI Ecosystem Vitality objective. All data are extracted from 2014 EPI – Indicator Metadata, unless otherwise stated (A Hsu et al. 2014a). The metadata sheet contains detailed descriptions of methods of both indicator and data source development. URL: http://epi.yale.edu/files/2014_epi_metadata.pdf

2014 EPI Objective: Ecosystem Vitality **Data source and metadata overview**						
Issue Category	**Indicator**	**Data Source(s) and Type**	**Coverage**	**Date Data Obtained**	**Proxies and Data Specificities**	**TNA**
Biodiversity And Habitat	*Terrestrial Protected Areas: National Biome Protection*	(UNEP-WCMC 2013) **Type**: GIS polygon shapefile	1990-2012	June 20, 2013	-	n/a
		(Olson et al. 2001) **Type:** ESRI Shapefile	circa 2000	2003	-	n/a
	Terrestrial Protected Areas: Global Biome Protection	(UNEP-WCMC 2013) **Type:** GIS polygon shapefile	1990-2012	June 20, 2013	-	n/a
		(Olson et al. 2001) **Type:** ESRI Shapefile	circa 2000	2003	-	n/a
	Marine Protected Areas	(UNEP-WCMC 2013) **Type**: GIS polygon shapefile	1990-2012	June 20, 2013	-	Log
		(VLIZ Maritime Boundaries Geodatabase VLIZ 2012) **Type:** Shapefile	2012	November 1, 2013	Averaging done when lacking AZE sites	Log
	Critical Habitat Protection	(Alliance for Zero Extinction 2005) **Type:** GIS point shapefile	2005	October 2, 2013	-	n/a
		(UNEP-WCMC 2013) **Type:** GIS polygon shapefile	1990-2012	June 20, 2013	-	

Table 27: Quantitative overview of the 2014 EPI Ecosystem Vitality objective. All data are extracted from 2014 EPI – Indicator Metadata, unless otherwise stated (A Hsu et al. 2014a). The metadata sheet contains detailed descriptions of methods of both indicator and data source development. URL: http://epi.yale.edu/files/2014_epi_metadata.pdf

2014 EPI Objective: Ecosystem Vitality Data source and metadata overview						
Issue Category	**Indicator**	**Data Source(s) and Type**	**Coverage**	**Date Data Obtained**	**Proxies and Data Specificities**	**TNA**
Climate And Energy	*Trend In CO2 Emissions Per Kwh*	(International Energy Agency (IEA) 2013) **Type:** Tabular	1960-2011	October 14, 2013	Developed from data provided by the IEA Unit: (Mt of CO2) (Data access requires purchase)	Log
		(International Energy Agency (IEA) 2013) **Type:** Tabular	1960-2011	October 14, 2013	Developed from data provided by the IEA Unit: (TWh) (Data access requires purchase)	Log
	Change Of Trend In Carbon Intensity	(World Resources Institute 2013) **Type:** Tabular	1990-2010	n/a	Data for 2010	Log
		(World Bank 2012) **Type:** Tabular	1960-2012	October 17, 2013	-	Log
		(International Monetary Fund 2013a) **Type:** Tabular	1980-2012	November 6, 2013	Country specific coverage	Log
		(CIA World Factbook 2013) **Type:** Tabular	1980-2012	November 6, 2013	Country specific coverage	Log
	Trend In Carbon Intensity	(World Resources Institute 2013) **Type:** Tabular	1990-2010	November 4, 2013	Data for 2010	Log
		(World Bank 2012) **Type:** Tabular	1960-2012	October 17, 2013	Data modification	
		(International Monetary Fund 2013a) **Type:** Tabular	1980-2012	November 6, 2013	Country specific coverage	
		(CIA World Factbook 2013) **Type:** Tabular	1980-2012	November 6, 2013	Country specific coverage	
	Access To Electricity	(World Bank & Sustainable Energy for All Initiative 2013) **Type:** PDF	1990-2010	November 10, 2013	Not included in calculation of EPI. Only displayed for reference to the calculation of Climate and Energy for LDCs	n/a

Table 28: Quantitative overview of the 2014 EPI Environmental Health objective. All data are extracted from 2014 EPI – Indicator Metadata, unless otherwise stated (A Hsu et al. 2014a). The metadata sheet contains detailed descriptions of methods of both indicator and data source development URL: http://epi.yale.edu/files/2014_epi_metadata.pdf

2014 EPI Objective: Environmental Health Data source and metadata overview						
Issue Category	**Indicator**	**Data Source(s) and Type**	**Coverage**	**Date Data Obtained**	**Proxies And Data Specificities**	**TNA** [2]
Health Impacts	*Child Mortality*	(United Nations 2013) **Type:** Tabular	1990-2013	October 12, 2013	Averages applied for specific countries	Log
Air Quality	*Household Air Quality*	(Bonjour et al. 2013) **Type:** Tabular	1990-2010 (in decades)	April 17, 2013	Measure total personal exposure when possible or rely on type of fuel as the risk factor, which indicates the total pollution released.	n/a
	Air Pollution Avg. Exp. To PM2.5	(van Donkelaar et al. 2015) (was embargoed) **Type**: Tabular	1998-2012 (central years for three-year rolling averages)	September 18, 2013	-	Log
		(NASA Socioeconomic Data and Applications Center hosted by the Center for International Earth Science Information Network (CIESIN) 2011) **Type**: ESRI GRID	2000	2013, exact date missing	-	Log
	Air Pollution PM2.5 Exceedance	(van Donkelaar et al. 2015) (was embargoed) **Type:** Tabular	1998-2012	September 18, 2013	-	n/a
		(NASA Socioeconomic Data and Applications Center hosted by the Center for International Earth Science Information Network (CIESIN) 2011) **Type:** ESRI GRID	2000	2013	-	n/a

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[2] Transformation needed for aggregation

Table 29: Quantitative overview of the 2014 EPI Environmental Health objective. All data are extracted from 2014 EPI – Indicator Metadata, unless otherwise stated (A Hsu et al. 2014a). The metadata sheet contains detailed descriptions of methods of both indicator and data source development URL: http://epi.yale.edu/files/2014_epi_metadata.pdf

2014 EPI Objective: Environmental Health **Data source and metadata overview**						
Issue Category	**Indicator**	**Data Source(s) and Type**	**Coverage**	**Date Data Obtained**	**Proxies And Data Specificities**	**TNA**
Water And Sanitation	*Access To Sanitation*	(World Health Organization & UNICEF 2013) **Type:** Tabular **URL:** No longer valid	1990-2011 (yearly values)	June 12, 2013	Interpolated using linear regression, according to the JMP methodology	Inverse logarithmic
	Access To Drinking Water	(World Health Organization & UNICEF 2012) **Type:** Tabular **URL:** No longer valid	1990-2011 (yearly values)	May 14, 2013	Some country specific data. Interpolated using linear regression, according to the JMP methodology	Inverse, logarithmic