MSc Program
Environmental Technology & International Affairs

An Empirical Study on the Relationship between Resource Footprints and Quality of Life in the Context of Environmentally Sustainable Development

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 13.06.2019

Affidavit

I, **STEFAN CIBULKA, LL.M., BSC (WU)**, hereby declare

1. that I am the sole author of the present Master's Thesis, "AN EMPIRICAL STUDY ON THE RELATIONSHIP BETWEEN RESOURCE FOOTPRINTS AND QUALITY OF LIFE IN THE CONTEXT OF ENVIRONMENTALLY SUSTAINABLE DEVELOPMENT", 94 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

Regression analyses show that the relationship between various resource footprints and quality of life generally follows a logarithmic path of development, while resource footprints and GDP per capita are linearly connected. Departing from the path of development and its development clusters, the concepts of decoupling, planetary and social boundaries can be added, showing that decoupling and green growth might not be sufficient to achieve environmentally sustainable development (ESD), if planetary boundaries have already been transgressed. Accordingly, a new model of ESD has been developed, supporting the concepts of a-growth and post-growth, which can be utilized as point of departure for further research towards a new, more comprehensive model. Development clusters along the path of development can be utilized for SDG prioritization and to adopt environmentally differentiated CDM strategies.

Preface & Acknowledgements

This Master's Thesis was written as a continuation of the bachelor's thesis "Interdependencies between Material Footprints and Quality of Life" (2017), which was also supervised by Dr. Stefan Giljum. As a lawyer with an economic background I applied for the postgraduate program "Environmental Technology & International Affairs" at the Diplomatic Academy of Vienna and the TU Vienna, an interdisciplinary program with courses in law, politics, history, economics, natural sciences and technology. Following that spirit, I decided to build upon my bachelor's thesis, by focussing on key issues, expanding the scope and increasing the degree of interdisciplinarity at the same time.

In that regard I would like to thank our Academic Director Prof. Dr. Hans Puxbaum, who has supported my proposal, and my supervisor, PD Dr. Stefan Giljum, research group leader at the Institute for Ecological Economics at the WU Wien, for again supervising my thesis with great enthusiasm. Furthermore, I would like to thank Prof. Dr. Jesus Crespo Cuaresma, Head of Macroeconomics at the WU Wien and lecturer at the Diplomatic Academy, and Prof. Ing. Dr. Verena Winiwarter, Institute of Social Ecology at the BOKU, for contributing to my thesis as co-supervisors, together enabling me to conduct research beyond the limits of the subject. Finally, I want to thank my partner Linda Rothauer, MSc, psychologist with a background in statistics, for supporting me mentally and with her statistical expertise throughout my work.

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List of Abbreviations

/cap	per capita
abs	absolute
avg	average
BLI	Better Life Index
CDM	Clean Development Mechanism
CEE	Central Eastern Europe
CF	Carbon Footprint
DMC	Domestic Material Consumption
E-SHDI	Eco-sustainable Human Development Index
EI	Environmental Impact
ESD	Environmentally Sustainable Development
EU	European Union
EWEB	Environmental Efficiency of Well-being
ET	Emission Trading
exby	explained by
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GNH	Gross National Happiness
GNI	Gross National Income
GSM	Green Solow Model
HDI	Human Development Index
HSDI	Human Sustainable Development Index
IHDI	Inequality-adjusted Human Development Index
JI	Joint Implementation
LF	Land Footprint
MDG	Millennium Development Goal
MENA	Middle East & North Africa
MF	Material Footprint
MRIO	Multi-regional Input-Output-Analysis
NDC	Nationally Determined Contribution
OECD	Organization for Economic Cooperation and Development
PB	Planetary Boundaries
PPP	Purchasing Power Parity
QL	Quality of Life
RES	Unstandardized residuals
RF	Resource Footprint
SD	Sustainable Development
SDG	Sustainable Development Goal
SEE	South Eastern Europe
SHDI	Sustainable Human Development Index
UN	United Nations
UNCBD	UN Convention on Biological Diversity
UNCCD	UN Convention to Combat Desertification
UNCED	UN Conference on Environment and Development
UNDP	UN Development Programme
UNDDR	UN Office for Disaster Risk Reduction
UNEP	UN Environment Programme
UNFCCC	UN Framework Convention on Climate Change
UNSDNS	UN Sustainable Development Solutions Network
UNSTAT	UN Statistics Department
WF	Water Footprint
WHR	World Happiness Report
ZRE	Standardized residual

1. Introduction

The master's thesis at hand can be regarded as the continuation of the bachelor's thesis of the same author (Cibulka 2017). In that thesis, interdependencies between material footprints and quality of life indicators were examined, suggesting an overall path of development and the possibility to establish development clusters. These aspects are taken up as a point of departure for this thesis. Instead of material footprints of the year 2012 only, this thesis uses material, carbon and land footprints from 1990 to 2015 and water footprints from 1996 to 2005. These resource footprints (RFs) will be utilized together with quality of life, with the Human Development Index (HDI) as the most important indicator.

Prior to the analysis, the author will provide a brief overview over the history of sustainability as a political background; furthermore, the state of the art in economics will be examined, from neoclassical and environmental economics, over planetary and social boundaries, decoupling and circular economy to the discussion about degrowth, green growth, a-growth and post-growth. In the following, a short reflection of Gross Domestic Product (GDP), development and happiness indicators and an explanation of the concept of resource footprints leads to the formulation of five hypotheses, which will be the basis for the subsequent analysis.

The key analyses will be an overall regression where the HDI is explained by each of the footprints (reaching a number of cases of about 4000) and a comparison between HDI, happiness index of the world happiness report and GDP/cap, followed by a disaggregated analysis for each footprint component, a timeline analysis and a cluster analysis based on the residuals of the regression. The results of this analysis will be utilized in the light of the theoretical concepts presented before, leading to a model containing several factors related to environmentally sustainable development. Finally, the question how the model can be made compatible with other models, and how it can be applied in the context of the UN Sustainable Development Goals (SDGs), will be assessed.

2. Theory and Methodology

2.1. Political Background: History of Sustainable Development

The term "sustainability" is derived from "sustained yield", originally referring to forestry (Winiwarter 2007). It was first used in Germany in the course of a deforestation crisis in the early 18th century and can be considered as the normative concept that no more wood should be cut than would grow in the same area over the same time. In 1972, the *Club of Rome* firstly brought up the scarcity of non-renewable resources as an issue of modern economics, contesting the paradigm of economic growth in its bestseller "Limits to Growth" (Meadows, et al. 1972). The *Club of Rome*, describing itself as "an organisation of individuals who share a common concern for the future of humanity and strive to make a difference" (The Club of Rome 2019), has issued dozens of reports since, most of them directly linked to sustainability and sustainable development.

The "Declaration of the United Nations Conference on the Human Environment 1972" was the result of the first international conference dealing with the issue of sustainability. It led to 26 principles, with principles 1, 2, 3 and 5 describing sustainability. In the following year, the *United Nations Environment Programme* (UNEP) was founded, also linking protection of the environment to international and intergenerational equity and fairness (Winiwarter 2007). The report "Our Common Future" of 1987 defines sustainable development as meeting "the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987). This so-called "Brundtland Report" also gives an overview about common challenges, naming population growth, food security, species and ecosystems, energy, industry, and even urbanization; what is more, management of the global commons "oceans", "space" and Antarctica, conflict management and institutional and legal issues are dealt with as "common endeavours".

Five years later, in the *United Nations Conference on Environment and Development* (UNCED), the so-called *Rio Earth Summit 1992*, the *UN Framework Convention on Climate Change* (UNFCCC), the *UN Convention on Biological Diversity* (UNCBD), the *UN Convention to Combat Desertification* (UNCCD) and the "Agenda 21" were adopted, the latter being an action plan concerning sustainable development. The plan contained four sections: (1) social and economic dimensions; (2) conservation and management of resources for development; (3) strengthening the role of major groups; (4) means of implementation. Developed in the follow-up meetings to Rio 1992 and finally launched after the Millennium Summit in September 2000, the "Millennium Development Goals" were the first comprehensive framework to be developed, which contained "Environmental Sustainability" as the seventh of the eight goals. These are: (1) eradicate extreme hunger and poverty; (2) achieve universal primary education; (3) promote gender equality and empower women; (4) reduce child mortality; (5) improve maternal health; (6) combat HIV/AIDS, Malaria and other diseases; (7) ensure environmental sustainability; (8) global partnership for development (United Nations 2019).

Under the other UN conventions mentioned above, several target frameworks concerning their specific scope have been adopted. Under the UNFCCC, the *Kyoto Protocol* (1997) and the *Paris Agreement* (2015) were introduced, advocating mechanisms such as the *Clean Development Mechanism* (CDM), *Joint Implementation* (JI) and *Emissions Trading* (ET). The CDM enables developed countries to carry out emission reduction projects in developing countries, thereby earning emission credits, which can be used to meet their national emission reduction targets; JI allows countries to trade emission reductions among each other; under ET, systems like the European Union's emissions trading scheme have been introduced (Oberthür and Ott 1999).

Under the *Paris Agreement*, every signatory state is obliged to develop their own "Nationally Determined Contributions" (NDCs) that have to be published, and which are intended to trigger domestic mitigation measures (UNFCCC 2019). The UNCBD, for example, has led to the adoption of the "Aichi Biodiversity Targets" for the period 2011-2020. Under the UNCCD, the "Land Degradation Neutrality Target Setting Programme" was introduced in 2015, leading to voluntary LDN targets. The *UN Office for Disaster Risk Reduction* (UNDRR), established in 1999, first came up with the "Hyogo Framework for Action" 2005-2015, followed by the "Sendai Framework for Disaster Risk Reduction" 2015-2030.

Following the *UN Conference on Sustainable Development* 2012 (Rio+20), the "Sustainable Development Goals" (SDGs) as a successor framework for the MDGs were prepared. In 2015, at the UN General Assembly, the *Agenda 2030* was adopted, with 17 SDGs at its core. These are: (1) end poverty in all its forms everywhere; (2) end hunger, achieve food security and improved nutrition and promote sustainable agriculture; (3) ensure healthy lives and promote well-being for all at all ages; (4) ensure inclusive and equitable quality education and promote lifelong learning opportunities for all; (5)

achieve gender equality and empower all women and girls; (6) ensure availability and sustainable management of water and sanitation for all; (7) ensure access to affordable, reliable, sustainable and modern energy for all; (8) promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all; (9) build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation; (10) reduce inequality within and among countries; (11) make cities and human settlements inclusive, safe, resilient and sustainable; (12) ensure sustainable

Figure 1: Sustainable Development Goals (United Nations 2019)

consumption and production patterns; (13) take urgent action to combat climate change and its impacts; (14) conserve and sustainably use the oceans, seas and marine resources for sustainable development; (15) protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss; (16) promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels; (17) strengthen the means of implementations and revitalize the global partnership for sustainable development (see Figure 1; (United Nations 2019)).

The 17 SDGs are operational goals to address the key issues dignity, people, planet, partnership, justice and prosperity. Apparently, the environment plays a much bigger role than in the MDGs, and most of the targets from other UN frameworks are also included. The SDGs are subdivided into 169 targets, which are to be measured by 232 indicators.

The targets contain specific stipulations, e.g. how an index is supposed to develop, or which steps have to be taken in order to reach the respective SDG. The indices are foreseen as measures of achievement, disaggregated, where relevant, by income, sex, age and race. The characteristics of these indicators vary widely between the SDGs. While a large number is directly referring to socioeconomic data (proportion of population, socioeconomic rates), quite a few cannot be derived from economic data provided by governments; in particular the SDGs linked to planet and prosperity are often referring to indicators based on scientific data. Accordingly, the SDGs have been described as a more integrated system than the MDGs, as a network of targets, requiring studies of biophysical, social and economic systems (Le Blanc 2015), and of positive and negative interactions within the network (Nilsson, Griggs and Visbeck 2016).

2.2. Background in Economics

2.2.1. History of Neoclassical, Environmental and Ecological Economics

In order to provide a comprehensive overview about neoclassical, environmental and ecological economics it seems essential to start with the "Solow Model" from 1956 (Solow 1956). It explains economic growth as convergence to an equilibrium of investments and depreciation, based on a neoclassical "Cobb-Douglas production function" (containing the neoclassical assumption of only two input factors, labour and capital, which are substitutable). According to this model, economic growth in the long term is only possible through technological progress (input efficiency). Technology, population growth and resource use were at first not included in the model, but subsequently added over the following decades.

So far, environmental factors have solely been treated from the input side. However, as pollution from SO_2, VOC, NO_x and aerosols had become an important issue over the second half of the 20th century, economists started considering pollutants in their models. The "Environmental Kuznets Curve" (EKC) is a theoretical, inverted U-shaped curve, which is based on the Kuznets Curve (Kuznets 1955). The Kuznets Curve explains inequality by income per capita, saying that with increasing income, inequality would initially rise and later decrease. The EKC implies the same for pollutants, which are said to increase with economic growth at first, but beyond a certain income decrease again (Grossmann and Krueger 1991). Put together with the Solow Model, the EKC was used in the "Green Solow Model" (GSM) by *Brock* and *Taylor* (2004). Simplified to one sentence, the GSM explains the initial rise of pollution by economic growth, which decelerates when reaching the equilibrium along the Cobb-Douglas production function; at the same time, there is a permanent decrease of pollution due to improved technologies (an improvement that is assumed to be constant).

The EKC had already been doubted before the GSM was developed (Yandle, Bhattarai and Vijayaraghavan 2002), since it could hardly be found in empirical studies. If at all, it could be found for pollutants with immediate impact, such as SO_2, VOC, NO_x and aerosols. Long-term emissions (such as greenhouse gases, GHGs) and environmental impacts like declining biodiversity would not follow an Environmental Kuznets Curve, and their emissions could rather be subsumed under the tragedy of the commons (Mills and Waite 2009). By using well-being data instead of income per capita as explanator of biophysical stress, even the inverse of the EKC has been found (Dietz, Rosa and York 2012); recent studies have found a strictly increasing linear or cubic relationship between Gross Domestic Product (GDP) per capita and resource use, with particularly high elasticities when using material footprints instead of domestic material consumption (Pothen and Welsch 2019).

Returning to the aspect of resource depletion and waste, the neoclassical theory was upheld in mainstream economics over the following decades, adapted by adding natural resources as a simple input factor. This implies that now capital, labour and resources are substitutable input factors (Solow 1974, Stiglitz 1979); as an extension for natural resource scarcity as a possible limit to economic growth, "Hartwick's rule" was adopted, saying that all rents from non-renewable resources should be invested, thereby avoiding declining consumption in the future (Hartwick 1977). Economists like *Daly* and *Georgescu-Roegen* strongly contested the neoclassical theory starting in the late 1970s (Georgescu-Roegen 1979), leading to an intensive debate about the growth model in the context of resource use (see for example the discussion in *Ecological Economics* 22, 1997 (Daly 1997, Stiglitz 1997)). *Stiglitz* argues in favour of substitutability, stating that changes in technology would reduce the amount of physical inputs required, and that output could be measured in values, not in physical units. Empirical evidence, however, shows that higher input efficiency has usually led to even higher resource use, because even more is consumed ("Jevons' paradox" (Mayumi, Giampietro and Gowdy 1998), caused by so-called "rebound effects" (Pfaff and Sartorius 2015)).

In the following (see for a comprehensive overview Hanley, Shogren and White 1997, and the new issue 2016), the "Environmental Economics" approach, embedded in neoclassical economics, focusses strongly on market failures and how they could be avoided, meaning, how externalities could be internalized (e.g. through taxes, tariffs, quotas, subsidies (Baumol and Oates 1971)) and how common goods could be regulated (e.g. better defined property rights; also compare the eight principles for managing the commons (Ostrom 1990)). Furthermore, environmentally adjusted national accounts have been proposed. For most of these purposes, a valuation of the input factors in monetary units is necessary, which has been criticised as impossible and inadequate, since values are defined by the markets and thus by consumer preferences (which do not automatically include ecological considerations), and because the actual environmental impact can hardly be measured. In "Ecological Economics", on the other hand, physical units are used, putting the biophysical relations between the socio-economy and the environmental as well as environmental resilience into the centre of its considerations (Common and Perrings 1992). As a result, according to *Common* and *Perrings*, the concept of consumer sovereignty cannot be upheld, and even correct valuation of consumer goods would possibly not lead to a sustainable outcome.

Given all these conceptual differences, which can also be circumscribed with "weak" and "strong" sustainability (Rennings and Wiggering 1997), according to a cluster study based on a survey, both narratives share a few common thoughts: In both schools of thought, ecological, societal and economic dimensions can be found; furthermore, criticism of pure economic growth seems to become more common (Illge and Schwarze 2009). In the following chapters, the author explains several important concepts that have been developed over the past twenty years: Planetary boundaries and doughnut economics as the natural and cultural framework we are working in; decoupling, green growth versus degrowth and circularity as possible ways to manage humankinds behaviour within these boundaries; GDP versus other measures of well-being and happiness to define what we want to maximize within these boundaries; and environmental footprints as consumption based, genuine measures of environmental pressures. Regardless of the respective paradigm, these concepts will be used to interpret the results of the analysis, leading to a multi-compatible model.

2.2.2. Planetary Boundaries and Doughnut Economics

The concept of sustainability has always been closely linked to the question, how much of a resource can at maximum be used at a given time, without compromising the use of the same resource in the future. While the first theories, as explained above, were technologically idealistic and normatively constrained to investment patterns, the safe minimum standard approach goes one step further (Hanley, Shogren and White 1997). Coming from the area of decision making under uncertainty, it requires the identification of a certain stock of a natural resource or organism that must be preserved, unless the pressure is proven harmless. Exceeding such limits can lead to unexpected threshold effects (Perrings and Pearce 1994). Based on the concept of safe minimum standards and the precautionary principle, *Rockstroem* introduced the new concept of planetary boundaries (Rockstroem 2009).

Taking a look at Figure 2 we can see the inner cycle (green) as the safe operating space below the boundaries, wherein humankind is expected to operate safely; the second cycle (yellow) illustrates the area of increased risk; beyond that point (red area), non-linear threshold effects on climate or other biophysical factors can be expected. Nine of these planetary boundaries have been defined (Steffen, et al. 2015); however, not all of them are quantified so far. The planetary boundaries after *Steffen, Rockstroem et al* are: Climate change, novel entities (compounds potentially leading to chemical pollution), stratospheric ozone depletion, atmospheric aerosol loading, ocean acidification, biochemical nitrogen and phosphorus cycle, freshwater use, land system change, biosphere integrity (subdivided into functional diversity and genetic diversity). In 2015, genetic diversity loss, nitrogen cycle and phosphorus cycle were already beyond the point

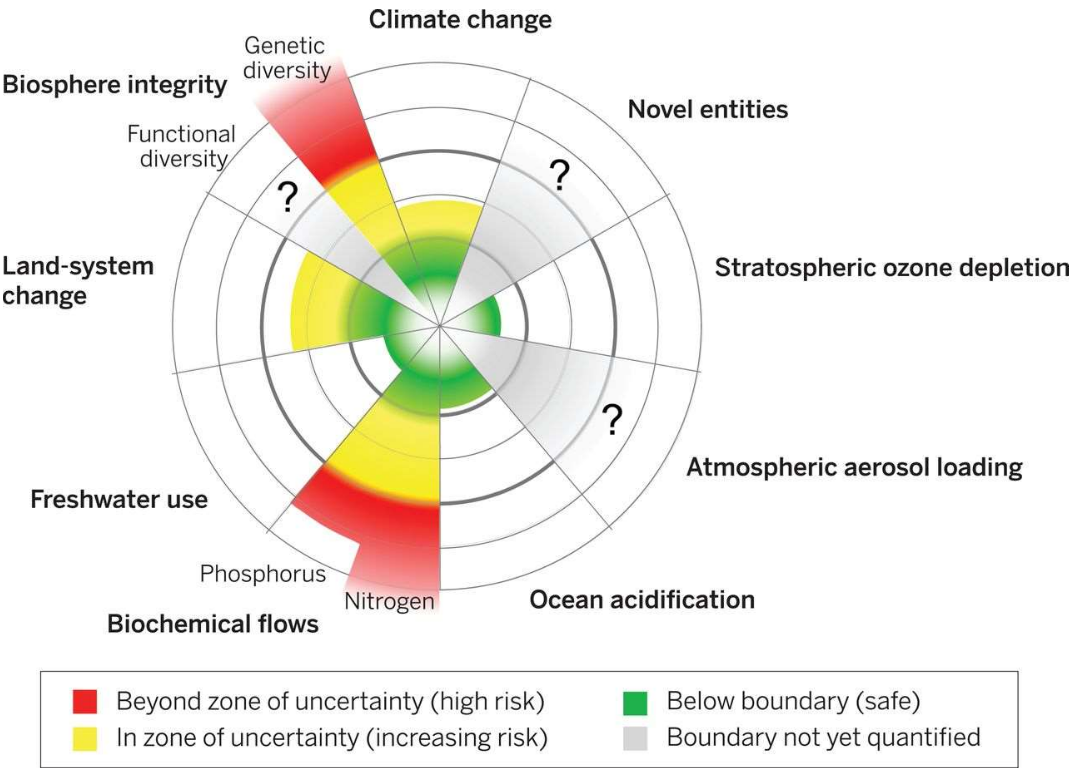


Figure 2: Planetary Boundaries (Steffen, et al. 2015)

of uncertainty; climate change and land-system change were in the yellow area, thus in the area of uncertainty. Moreover, *Steffen, Rockstroem et al* have found climate change and biosphere integrity to be the two "core" PBs, as they severely interfere with other PBs and are fundamentally important for the environmental system as a whole (Steffen, et al. 2015). A recent publication links PBs to the SDGs, examining four possible scenarios until 2050; based on them, five policy recommendations were issued, emphasising urgency and the need to take transformative measures (Randers, et al. 2018).

Based on this concept, *Raworth* developed the doughnut model, by linking planetary boundaries to what she calls social boundaries (Raworth 2012, Raworth 2017). The social boundaries are derived from the governments' priorities for the Rio+20 summit in 2012. Figure 3 shows the doughnut model, with the doughnut shape itself as the "safe and just space for humanity". The sectors are scaled in a way that the social boundaries are the inner cycle and therefore, must be exceeded, and the planetary boundaries are the outer cycle, and hence must not be transgressed. Although, of course, the units used for each sector are not comparable among each other, and thus the arrangement can be considered arbitrary, the doughnut provides an excellent thinking model, of what should be the normative basis of economic policies; namely, providing a decent quality of life to all humans, while not exceeding planetary boundaries.

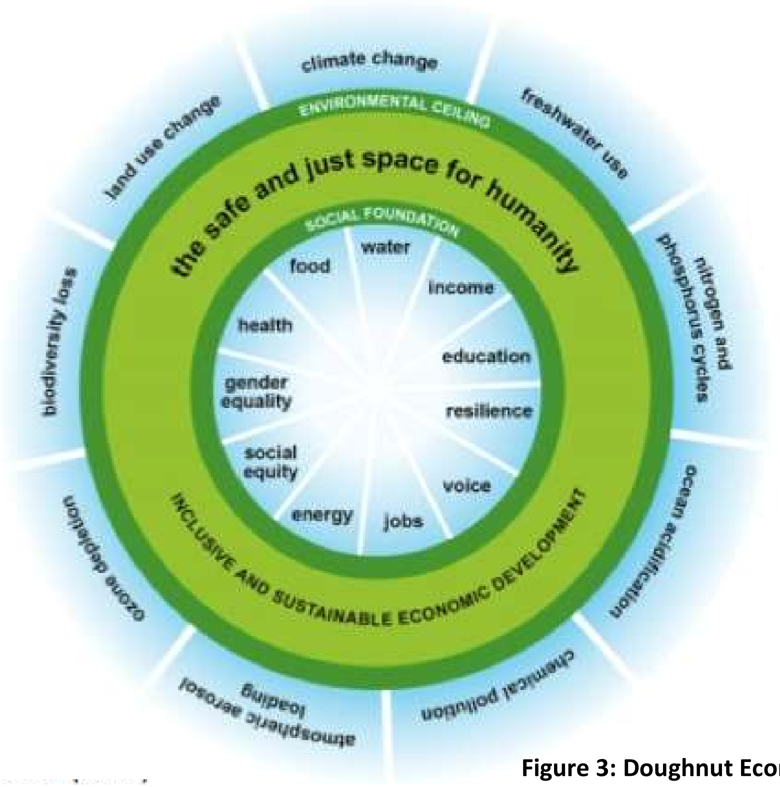


Figure 3: Doughnut Economics (Raworth 2012)

A paper, practically applying the doughnut model utilizing disaggregated planetary boundaries for over 150 countries, has shown that based on current data, links between social and planetary boundaries, universal achievement of the social boundaries would lead to an exceedance of the planetary boundaries by two to six times (O'Neill, et al. 2018). Not surprisingly, the study found that the more social goals are achieved, the more natural limits are transgressed. This, once again, underlines the necessity for a change of the development patterns towards achieving social development goals.

2.2.3. Decoupling and Circular Economy

In this chapter, a number of different approaches to the question, how sustainable development can be achieved, will be explained and compared. A very important concept to be explained in this context is that of "decoupling". The term originates from the strongly coupled developments of GDP and resource use (compare Figure 4 (Krausmann, et al. 2009)). Decoupling means that, although the GDP still increases, growth of material consumption slows down (relative decoupling) or even declines (absolute decoupling (Bringezu, et al. 2014, Fischer-Kowalski 2011)).

Without explicitly naming it "decoupling", first reforms of agricultural policies were discussed in the later 1980s (OECD 2011, OECD 2015), following the first attempts to highlight resource scarcity (Meadows, et al. 1972). Around the turn of the millennium, decoupling of economic growth and negative ecological effects became a widely acknowledged political objective (Schleicher-Tappeser, Hey and Steen 2000, Juknys,

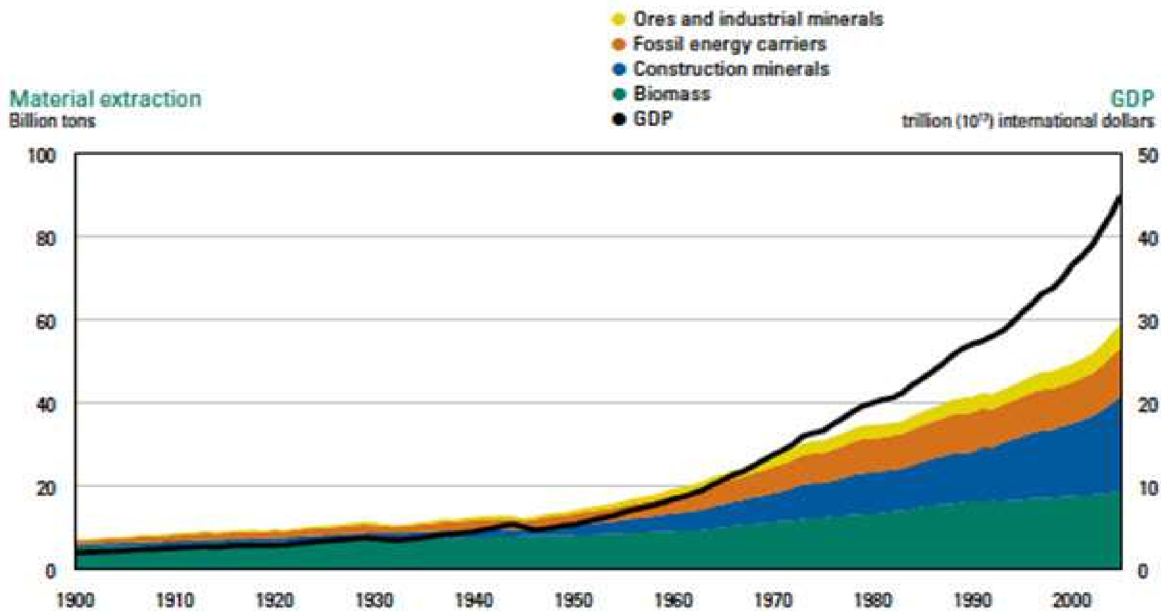


Figure 4: Coupled development of GDP (right y-axis, in trillion dollars) and Material Extraction (left y-axis, in billion tons); x-axis: timeline from 1900-2005 (Krausmann, et al. 2009)

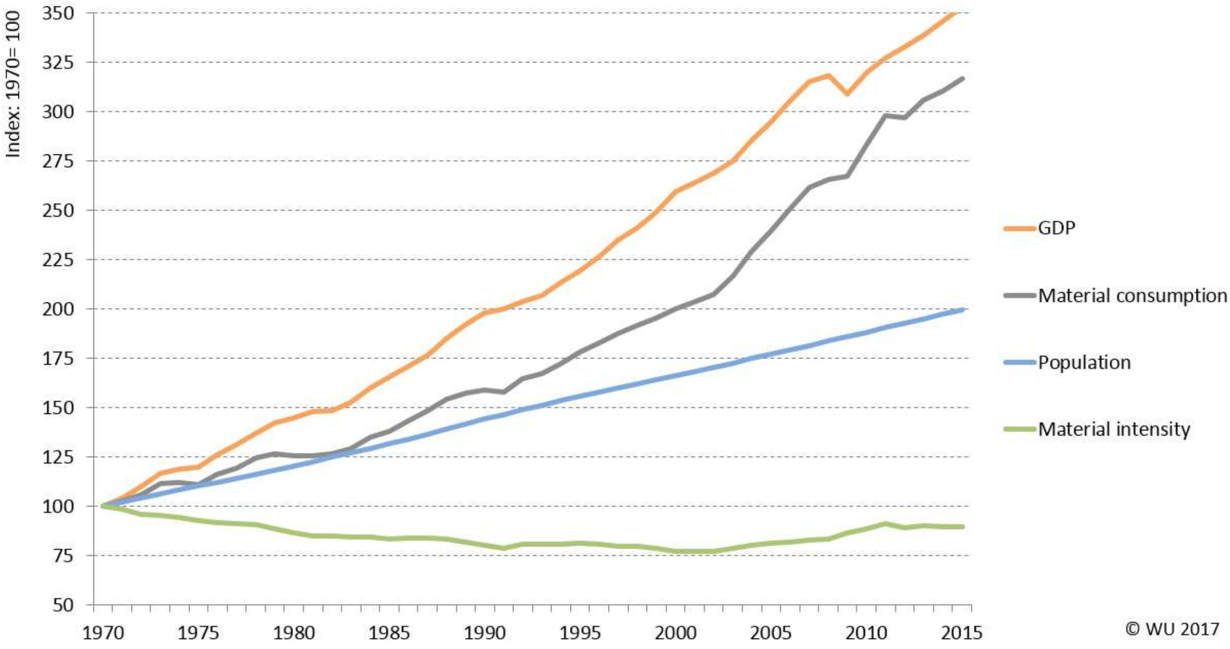


Figure 5: Decoupling; timeline from 1970-2015; change in %, 1970 = 100; GDP PPP, Material Consumption, Population, Material Productivity, Material Intensity, based upon the UN IRP Global Material Flows Database (WU Vienna / CSIRO 2017)

Miskinis and Dagiliute 2005, EEA Report 2016). On a global scale, analyses of resource extraction already pointed towards a partial decoupling between GDP and resource use, the correlation declined particularly between 1980 and the turn of the millennium. Since then, a re-coupling of the global resource extraction and the global GDP has been observed (Figure 5 (WU Vienna / CSIRO 2017, Dittrich, Giljum and Lutter, et al. 2012)), whereas energy and carbon emissions seem to remain relatively decoupled (Steinberger and Roberts 2010).

One of the most promising approaches for reducing material consumption is certainly the path towards a circular economy. It is particularly interesting to deal with, since circularity cannot be easily classified within economics and even sustainability, as comparative studies show (Geissdorfer, et al. 2017, Ghisellini, Cialani and Ulgiati 2016). Starting around the turn of the millennium, the concept of a circular economy gained more and more importance in China, which has already started suffering from resource scarcity and pollution due to the high economic growth over the 1980s and 1990s. In 2006, it became part of the national economic strategy (Yuan, Bi and Moriguchi 2006). In the European Union, an action plan towards a circular economy was adopted in 2015 (European Commission 2015, Mayer, et al. 2019), together with proposals to amending European legislative acts like the EU Landfill Directive, the EU Waste Directive, the EU Packaging Waste Directive, the EU Hazardous Waste Directive and the EU Electronic

Waste Directive. Authors have also emphasised the role of product services for a higher resource efficiency, for finally paving the way towards a circular economy (Tukker 2015).

The focus on waste shows that the concept of a circular economy is very strongly linked to the waste issue, following the waste hierarchy (1) prevention, (2) reuse, (3) recycling, (4) recovery, (5) disposal. This explains why circular economy cannot be easily classified in economic models, as for some of these elements the overall effects are unclear. Whereas many studies have acknowledged circular economy from beneficial, over conditional to strongly conditional for sustainability, other studies are also emphasising trade-offs with economic development (Geissdorfer, et al. 2017). Indeed, prevention (1) and reuse (2) might lead to negative effects on the primary and secondary sector; not without a reason, planned obsolescence became a major issue in developed countries over the past years, on the one hand maintaining economic growth, and on the other hand leading to enormous resource use in developing countries (Wieser 2016). Again, product services could make up at least parts of the economic losses, through gains in the tertiary sector (Tukker 2015). Recycling (3) can, also without subsidies, be beneficial, if the amount of energy needed for recycling is lower than for the initial production (mining, smelting, etc.); however, this is only true until a certain share of secondary material, above which the costs of recycling exceed the costs of primary production, leading to a commodity specific cost minimum (Stumm and Davis 1974, Gutowski 2008); this minimum can of course be shifted, by increasing energy and cost efficiency of recycling methods. Recovery (4), in particular energy recovery from solid municipal waste, is definitely ecologically desirable, but entails high costs; the same is true for sanitary landfilling or disposal under recovery of methane (5).

The first economic model including circular economy as an integral part was published by *George et al.* in 2015 (George, Lin and Yunmin 2015). It includes two factors of production, potentially recyclable resources and polluting resources, with the former being expressed as the actual recycling ratio times the waste stock. The model predicts that in the course of economic development, recyclable inputs gradually substitute polluting inputs, therefore leading to a point of turnaround. The detailed model would go beyond the scope of this thesis but appears to be a promising starting point for further research.

To conclude, the author shares the opinion of those who see the circular economy as conditional for achieving sustainable development, at least beyond a certain point of development or level of resource use. In that regard, further research on the particular effects of changes along the waste hierarchy and possible feedbacks (like substitution between sectors) would be of major importance for future models. How this issue is linked to economic growth and quality of life will be assessed in the discussion of the results, see Section 4.

2.2.4. Degrowth, Green Growth, A-Growth and Post-Growth

Alternative growth models have always been highly contested. In contrast to the conventional paradigm of continuous economic growth, there is a huge variety of alternative concepts. Degrowth is the most radical, claiming the necessity of negative economic growth; green growth wants to combine sustainability with positive economic growth; a-growth, non-growth or post-growth theories are rather conciliatory, looking for growth beyond production and consumption.

Starting few decades ago, most of the initial critiques against the growth paradigm were brought forwards in a comparably radical way. *Diamond*, for example, called the change from hunter-gatherer to agriculture the "worst mistake in the history of the human race" (Diamond 1987), thereby criticising the whole modernization of humankind. Also, in more recent literature, degrowth was claimed as the solution, following a radical critique against the consumption society and the economic liberalism as such (Latouche 2009). While these critiques might be interesting from a philosophical or anthropological point of view, it can be doubted that an immediate change of the economic system following these ideas would benefit most of the population. In that context, the criticism against the degrowth paradigm can be followed, since indeed, most of the positive developments over the last century would have been impossible without economic growth (Ben-Ami 2012), and the prosperity resulting from the economic growth cannot be overseen. However, conventional economic growth policies were in the past neither able to sufficiently handle the issue of market failures due to environmental pressures and impacts, nor to draw the right conclusions from resource scarcity, biodiversity loss and long-term pollution.

Jackson, as one of the scholars questioning the growth paradigm, openly acknowledges that economic growth is indeed necessary to provide the basic material opulence for prosperity, for basic entitlements like health or education, and for the functioning of the current economic system (particularly employment and social system). Nevertheless, under the title of "prosperity without growth", he pleads in favour of non-growth for already developed countries, to avoid ecological unsustainability (Jackson 2009). He thereby rejects relative decoupling as insufficient and emphasises the importance of absolute decoupling, i.e. a decline of resource impacts in absolute numbers, which is simply not feasible by merely increasing economic efficiency. *Kallis*, defending degrowth much stronger than *Jackson* does, additionally points out that rather than sticking with the growth paradigm, the mandate of basic institutions must be changed, away from economic growth towards a positive social development (Kallis 2011, Kallis, D'Alisa and Demaria 2015).

Introducing the concept of sustainability within the neoclassical growth model, *Hallegatte* has presented a model called "from growth to green growth" (Hallegatte, et al. 2012). He emphasises the role of growth in the reduction of poverty, child mortality and malnutrition, and the development of literacy and education. He also counters criticism that growth would cause increasing inequality, which would rather be caused by policies. Acknowledging that the story was not that simple regarding the environment, the model extends the Solow Model by explaining economic output via human capital, physical capital, labour and environment (as natural capital). Furthermore, an efficiency factor between 0 and 1 is added, accounting for imperfections in the market economy. The model assumes that if all externalities were included, a "Green GDP" could be calculated.

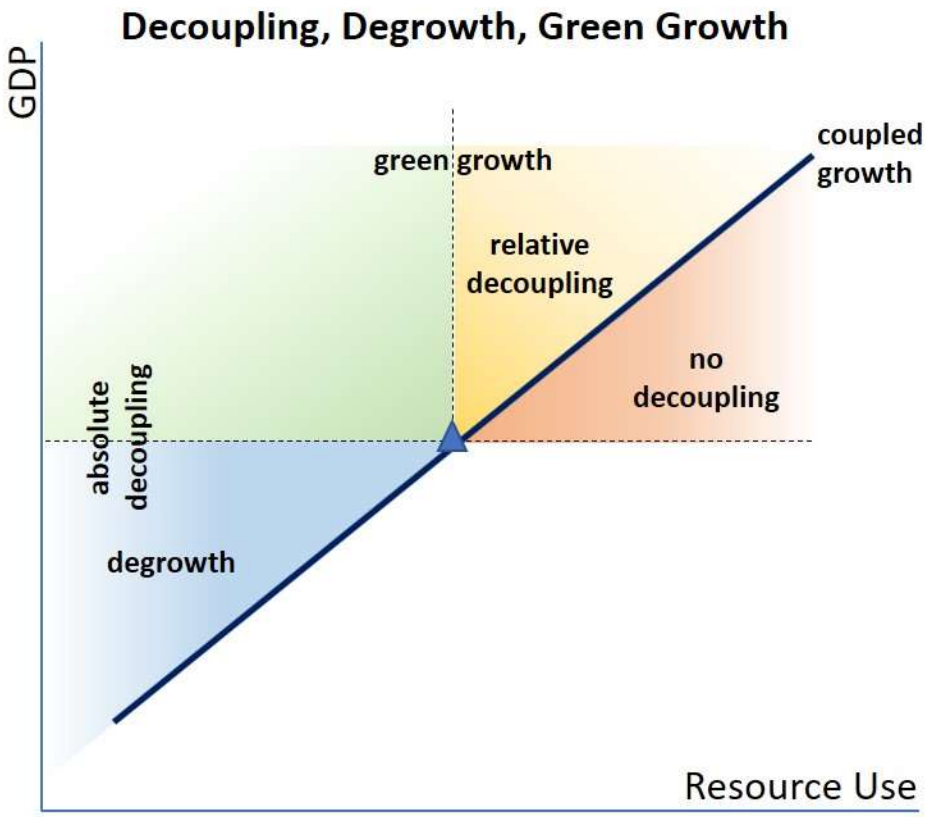


Figure 6: Decoupling, Degrowth, Green Growth

Introducing P_E as the effort dedicated in environmental policies, the model includes costs resulting from trade-offs, which can decrease the GDP in the following ways: (1) lower productivity due to more expensive or less productive technologies required to meet environmental targets; (2) lower physical capital as not all resources are made available; (3) demand-wise, price increases and shifts between sectors accounting for net losses in allocational efficiency. These impacts would actually lead to degrowth, if there were not certain advantages as well: (1) increase of inputs over the long term, due to better environmental protection, workers health and lower losses from disasters; (2) higher productivity due to less market failures; (3) upshifting production frontier by increased innovation and technology due to public intervention. Public intervention is clearly needed for all three advantages.

Figure 6 summarizes the models explained so far. The linear curve shows the relationship between natural resource use and GDP in a situation of fully coupled growth (see previous chapter and Section 3.2. (Krausmann, et al. 2009)). Starting from any point on the line, an upward movement along the line or to the upper right (red area) constitutes further unsustainable growth without decoupling. A movement towards the area between the coupled growth line and the dotted vertical line (yellow area) would be relatively decoupled growth; this can also be seen as green growth, as resource use relatively declines in comparison to economic output, and there is still economic growth. A movement to the upper left, towards the green area, would indicate absolute decoupling (as the level of absolute resource use declines), but still green growth, because the GDP would still increase. A movement to the blue area is also absolute decoupling, but from the economic point of view this area can be seen as degrowth. From this chart it would be clear that the green area should be the target area; however, this would overlook some very important developments, for example that the GDP is not anymore seen as the only measure of prosperity, and that resource use can be measured in multiple ways. Furthermore, planetary and social boundaries are missing.

That prosperity should be regarded as a concept consisting of multiple factors necessary for a decent life has already been mentioned in the context of degrowth, non-growth and green growth (Jackson 2009, Fritz and Koch 2014, van den Bergh and Kallis 2012, Hardt and O'Neill 2017). *Hallegatte*, from within the neoclassical framework, acknowledges that "green growth", as a positive net effect of the costs and advantages mentioned above, is most likely achievable if the GDP is adjusted by ecosystem services (Hallegatte, et al.

2012). That implies what *van den Bergh*, who also used to criticise degrowth in its conventional sense, names "a-growth" (van den Bergh 2011): Neither the maximization of the GDP, nor degrowth should be seen as the preferred economic strategy. Instead, environmental, social and economic policies can be pursued on the basis of indicators on quality of life, development or well-being. Consequently, this indifference towards the GDP can lead to economic growth, to non-growth or to degrowth. *Hardt and O'Neill* give an overview about more than twenty economic *post-growth* models (Hardt and O'Neill 2017), pointing out differences of monetary versus physical input-output models, system dynamics, stock-flow-consistency, and numerical versus analytical models. Post-growth – finally the last new term in this context – will now be used as the generic term of all concepts that do not solely rely on GDP growth.

That *Ben-Ami* (2012) polemically criticises these scholars, who do indeed work on prosperity, but trying to go beyond GDP growth, must be rejected as backward oriented, counterproductive and expendable. Instead, the author believes that the approaches summarized under post-growth could be used as an attempt of reconciliation between neoclassical and ecological economists. Assuming that all scholars working in this area want to foster prosperity and sustainability, and, agreeing that the GDP is not the optimal measure for that, "growth" itself becomes a neutral term that is used differently between different schools of economic thought. Attempts to find a common answer to the question, which aspect we want to maximize, will be displayed in the next chapter.

2.2.5. GDP, Development and Happiness

As established in the previous chapter, GDP is not anymore the undisputed index for the well-being of a society, not even for the economy. Comparing the literature on this issue (see sources cited in the previous chapter and below), there are several approaches to create alternative solutions, starting from adjusted GDP measures (e.g. including capital and pollution stocks and so depicting the destruction of stocks), measures combining GDP with other indices (such as the HDI and IHDI, see below), multi-factor indicators (based on many different economic data that are supposed to explain well-being), and subjective measures mainly based on surveys (like the Happiness Index). Other authors have suggested microeconomic adaptations like the "sustainable value added" (Figge and Hahn 2004).

This variety of approaches has consequently caused a congregation of terms, from economic output over development and well-being to happiness and satisfaction. Each of the terms requires an own definition, which is partially derived from economics, but also from sociology and psychology. The latter two, happiness and satisfaction, are already rather psychological terms then economic ones, therefore an approximation via standardized surveys or proxy models based on multifactor indicators is inevitable. At least, the author regards it as clear that the ultimate target of policies based on economic models should serve the development or well-being of the society, and the happiness or satisfaction of the individual, rather than serving as a self-sufficient indicator that is maximized for the sake of the economy itself.

One of the best-established indicators for quality of life, in this case called "development", is the Human Development Index (HDI). It was created by the United Nations Development Programme and contains three dimensions, decent standard of living, life expectancy and education (UNDP 2019). Decent standard of living is measured via the logarithm of the gross national income (GNI) per capita, thereby reflecting the declining marginal utility of increasing income. Life expectancy is expressed as estimated life expectancy at birth. Education consists of the two factors (1) average schooling duration of adults and (2) expected schooling duration of children.

According to the UNDP, the HDI was "created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone" (UNDP 2019); it is published in its Human Development Reports. However, the HDI is mostly based on averages and does not reveal details about the quality of life of the less privileged share of population. It does not automatically tell about happiness or satisfaction in a country in general, although there might be of course a relationship between happiness or satisfaction and development. Therefore, it would be particularly interesting, whether and if yes to what extent dimensions such as happiness or satisfaction diverge from the HDI (Cibulka 2017).

One of the insufficiencies of the HDI, that inequality is not displayed, has already been tackled in the "Inequality-adjusted Human Development Index" (IHDI). It displays the "cost of inequality", alternatively termed "loss to human development due to inequality". It is directly adjusted from the original HDI; thus, the UNDP also displays the ordinal descent of particularly unequal countries compared to other countries. For example, the United States achieved Rank 10 world-wide with an HDI of 0.920, but lost 10 positions with their IHDI (IHDI of 0.796, in 2015). Unfortunately, the IHDI is available for fewer countries and for a shorter time than the HDI, making is unsuitable for this thesis.

Another drawback, the lack of an environmental dimension, has been tackled by *Togtokh*, called "Human Sustainable Development Index". It re-calculates the HDI in a way that a fourth sub-index, namely per capita CO_2 emissions, is added before the normalization of the composite (Togtokh 2001); of course, this variable is lowering the index value of countries with high GDP/cap, and thus HDI. Later studies have found the HSDI a step ahead of the existing HDI, but still insufficient to fully include environmental sustainability (Bravo 2014). In this thesis, anyway, this extension does not play an important role; first, due to the lack of data, second, as measures of well-being or development or happiness are assessed against resource use as such, not as an environmentally adjusted index. The same is true for the "environmental efficiency of well-being" (EWEB (Reid, et al. 2005, Knight and Rosa 2011)), the "sustainable human development index" (SHDI (Kai, et al. 1998)) and the "eco-sustainable human development index" (E-SHDI (Türe 2013)). Concerning all these approaches, the author sees it as problematic to aggregate information on resource use or emissions with development factors into one number, making it impossible to assess changes of one of them towards the others.

Compared to the rather economic term "development" that has been used for the HDI, "happiness" or "satisfaction" can rather be found in sociology or psychology. Among the methods indicated above, multifactor models or surveys are the two possibilities to set up indicators for these terms, however, always with methodological drawbacks like inconsistencies or model errors. Possible proxy indicators for happiness could be health, safety, security, access to infrastructure, social standards, freedom of decision, or life perspectives (Cibulka 2017).

In 2008, by amending its constitution, the "Gross National Happiness" (GNH) was officially adopted as the goal of the government in the Kingdom of Bhutan (Article 9, para 2 of the Constitution of The Kingdom of Bhutan), after it has become one of the main national policies over decades (Shrotryia 2006). The first "World Happiness Report" (WHR) was issued in 2012 by the Sustainable Development Solutions Network (UNSDS 2019). For the WHR, independent experts use happiness-related data from the Gallup World Poll, namely the GDP per capita, social support, healthy life expectancy, freedom to make choices, generosity and trust in democratic institutions (explained by perceptions of corruption). WHR data are partially available back to 2005/2006; in 2019, 156 countries were ranked in accordance with their "life ladder" from zero (worst) to ten (best). Since 2013, the OECD issues the "Better Life Index" (BLI), with a large number of factors, such as housing, income, job situation, community, education, environment, civil engagement, health, safety, work-life-balance and even life satisfaction (OECD 2019). Unfortunately, the OECD BLI covers only OECD countries plus Russia and Brazil. Due to the wide range of relevant factors, the OECD BLI might play an important role in future studies (Cibulka 2017).

In this thesis, measures of development and happiness will be used to assess the relationship with environmental pressures. As it has already been done in existing research (Verhofstadt, et al. 2016, Tukker 2016, Dittrich, Giljum and Lutter, et al. 2012, Steinberger and Roberts 2010), the GDP per capita will, thereby, be substituted by some of the other indicators explained above. Due to the poor data availability of most indicators, in particular concerning the 1990s and early 2000s, mainly the HDI will be used. Additionally, a statistical comparison between GDP PPP per capita, HDI and the happiness index of the World Happiness Report will be conducted, showing differences in the overall shape of the regression. In the following chapter, the measurability of environmental pressures will be assessed, explaining why the indicators as presented so far will be set in a relationship with resource footprints (RFs).

2.2.6. Resource Footprints

Resource use or emissions are often measured only from a territorial (or production-oriented) perspective. For example, the Kyoto Protocol and the Paris Agreement are based on the amounts of emissions within the territory of each country, other indicators consider direct trade flows. For example, in the case of material flows, the indicator called "domestic material consumption" (DMC) is calculated as domestic extraction plus physical imports minus physical exports. However, this indicator does not contain indirect effects that result from upstream flows of imports and exports, therefore the DMC of net importers tends to be lower than the actual resource consumption along the whole supply chain, while the DMC of net exporters appears to be higher. Accordingly, industrialized nations have shown declining DMCs, which could be interpreted as absolute decoupling. However, this approach is misleading, since most of the resources used for imported goods remain in the countries of origin in the form of waste or cheap by-products (Wiedmann 2015, Cibulka 2017). This can lead to the wrong finding that developing countries were responsible for very high levels of resource use, compared to the allegedly resource efficient industrialized countries, although negative externalities are only shifted across the globe (Giljum 2016, Weinzettel, et al. 2013). In fact, the other side of the same medal is that industrialized countries are becoming increasingly dependent on imports from resource-extracting emerging countries (Tukker 2016).

Footprints or consumption-based indicators, in contrast, account for the whole stream of indirect resource use, thereby attributing resource extraction and emissions along the supply chain to the final product, and so to the consumer as the trigger of production. For many countries, declining domestic resource use is hence outweighed by the particularly high resource extraction in other world regions (Dittrich, Giljum and Lutter, et al. 2012, Dittrich, Giljum and Polzin, et al. 2011). Footprints allow describing and comparing production processes and supply chains with each other, analysing the development of resource use over time, and analysing dependencies between countries and the relationship between resource use and socioeconomic factors. The latter approach, in the form of per capita footprints, will be pursued in this thesis.

In this thesis, four types of footprints will be used and generally addressed as "resource footprints" (RF): (1) material footprints (MF), (2) carbon footprints (CF), (3) land footprints (LF) and (4) water footprints (WF). MFs are composed of the material types minerals, metal ores, fossil fuels and biomass. Components of the CF are carbon dioxide, methane, nitrous oxide, perfluorocarbons, hydrofluorocarbons and sulphur hexafluoride. LFs can be divided into extensive and intensive forestry, annual and permanent crops, and pasture (built-up land will be neglected in this thesis due to data limitations, see below). According to source and use, green water, blue water and grey water are distinguished as components of the WF. The source for material footprints, carbon footprints and land footprints in this thesis is the "sustainable consumption and production hotspots analysis tool" of UN Environment (SCP-HAT (WU Vienna / CSIRO 2019)), developed by the Institute for Ecological Economics at the Vienna University of Economics and Business (WU Vienna, Austria) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO, Australia). The source for water footprints is the Water Footprint Network (Hoekstra 2019).

Material footprints can be calculated in different ways, the methods range from coefficient-based approaches to input-output analysis, and combinations of both (Giljum 2016, Lutter, Giljum and Bruckner 2016). The coefficient-based approach is not restricted by the need to cluster data to product groups or aggregated economic sectors and can be used for a wide range of products, while it is not comprehensive along the supply chain.

Input-output analysis on the global level uses world-wide environmental datasets in absolute physical terms, enabling an analysis along the whole supply chain back to the origin without double counting. The downside is that data need to be clustered to the level of economic sectors and product groups (Tukker 2014). The SCP-HAT uses multi-regional input-output analysis data from the Eora database (Schmelz, et al. 2018), which provides data for more than 180 countries with time series back to 1990 (Lenzen, Moran, et al. 2013, Lenzen, Kanemoto, et al. 2012).

The data sources for the carbon footprints in the SCP-HAT are the PRIMAP-hist database of the Potsdam Institute for Climate Impact Research (Gütschow, Jeffery, et al. 2017, Gütschow, Jeffery, et al. 2016), supplemented with data from the EDGAR database (European Commission Joint Research Centre (Olivier and Janssens-Maenhout 2012)). Without going into the details of data processing it is worth mentioning that for the sake of calculating carbon footprints, CO_2 equivalents must be calculated. For this purpose, the correspondence tables of Global Warming Potential 100 (short term, GWP100) and the Global Temperature Change Potential (long term, GTP100) can be applied, with multiplicators for many different compounds (Schmelz, et al. 2018). For this thesis, data calculated via the GWP100 have been used.

For calculating land footprints, the SCP-HAT follows the method developed by *Chaudhary et al.* (Chaudhary, et al. 2015, Schmelz, et al. 2018), containing data for annual and permanent crops, pasture, extensive and intensive forestry. Urban land use was not available in the database when the data were processed for this thesis; land use for industrial activities like mining or built-up land are not yet included in the database. Like the MF and CF, the LF is available in SCP-HAT for the period 1990-2015, for more than 170 countries.

In contrast to the MF, CF and LF, water footprints are not yet included in the SCP-HAT, as data are only available for the period 1996-2005. Therefore, its role in this thesis will be rather limited. The WF consists of green water, which can be defined as the consumptive use of rain water (renewable water use), blue water as the consumptive use of ground and surface waters (non-renewable water use) and grey water as the theoretical amount of water needed to dilute polluted water to an extent to make it innocuous for the environment (Hoekstra and Mekonnen 2012). Consumptive use can be defined as the amount of water evaporated in the course of the production (e.g. from a field during the growth of a plant), evapotranspiration from the product itself, and water incorporation into the product.

Another popular footprint indicator, which will not be dealt with in this thesis, is the ecological footprint. It was introduced by *Wackernagel and Rees* (Wackernagel and Rees 1998, Toth and Szigeti 2016) and expresses the resource intensity of humans by the land area necessary to sustain current levels of resource consumption and waste discharge. The ecological footprint also includes "virtual land", i.e. land that is required to sequestrate CO_2 emissions in the form of wooden biomass. It has early been shown that the total ecological footprint does already exceed the total land area on earth. However, due to the combination of many possible resource factors, using this footprint would probably be methodologically convoluted and unprecise for the purposes of the thesis at hand. As the first composite footprint it might, nevertheless, be used in sustainable development models to get a first overview of a persons' or a countries' resource intensity.

Following the approach of *Verhofstadt*, *Tukker* and other scholars (Verhofstadt, et al. 2016, Tukker 2016, Dittrich, Giljum and Lutter, et al. 2012, Steinberger and Roberts 2010) and the previous paper of the author (Cibulka 2017), resource footprints will be used in the context of quality of life, thereby utilizing data from the SCP-HAT tool. In the following chapter, this context will be tackled in the form of hypotheses, which can be analysed in the next section.

2.3. Methodology

Following the approach already pursued in his previous thesis, the author analyses statistical interdependencies between environmental footprints and quality of life. While in the previous thesis only material footprints of the year 2012 were taken into account, the thesis at hand will use MF, CF and LF for the whole period from 1990 to 2015 (Schmelz, et al. 2018), and the average WF for the period 1996-2005 (due to limited data availability (Hoekstra and Mekonnen, The water footprint of humanity 2012)). As measures for quality of life, mainly the HDI will be used, as it is the only index available as of 1990 (UNDP 2019). For a comparison between indices, the Life Ladder of the World Happiness Report will be used for the period 2006-2015 (UNSDS 2019), as well as the GDP per capita for the same time frame (World Bank 2017). Supplementary population data are taken from the UN Population Division (population size (UN Population Division 2015)) and the World Bank Development Indicators (population density (World Bank 2017)).

In this thesis, the following hypotheses will be examined:

1. The overall relationship between resource use (statistically used as predictor) and quality of life (statistically used as dependent variable, measured as HDI and Happiness Index) follows a logarithmic regression curve, accounting for the diminishing marginal utility of resource use.
2. The regression curve examined in (1) differs from the relationship between resource use (predictor) and GDP per capita (dependent variable), which would rather follow a linear regression curve.
3. If (1) cannot be rejected, countries with similar development patterns can be clustered according to their position and development along the logarithmic regression curve.
4. If (1) and (2) cannot be rejected, an analytical model can be derived which is compatible for connections to economic growth (green growth) models and planetary boundaries. This model can be utilized to examine possible impacts of policies from both an ecological and macroeconomic point of view.
5. If (3) cannot be rejected, clusters and typical development patterns could be used for the prioritization of Sustainable Development Goals, in cases of negative interactions on the SDG target level.

Before starting the analysis of environmental footprints and quality of life, the results of the environmental footprints provided by SCP-HAT and the Water Footprint Network will be presented. Thereafter, for the examination of hypotheses (1) and (2), numerical methods using IBM SPSS Statistics (Version 25) and Microsoft Excel will be applied. Via SPSS, logarithmic regression models are calculated, while Microsoft Excel is used to illustrate the results and carry out comparisons between linear and logarithmic regression lines. The resulting coefficients, R^2 values and statistical tests will be explained in the respective chapters. For details, please see Annex 2.

After the regression analysis, (3) the standardized residuals of the regression models will be used to form clusters, showing the position of a country in the model in relation to the overall regression curve. In addition to the statement whether a country is above or below the curve, or has transgressed it in either direction, the coordinate system can be further subdivided into development levels (thresholds), resulting in at least six clusters. Descriptive and explorative methods can additionally be used to explain each cluster, and moreover, analyse typical properties and development patterns. For this purpose, timeline analyses will be used.

The scope of hypothesis (4) is strictly limited to a theoretical, analytical model; a numerical examination of the interdependencies between the regression curve tested in (1) and (2) and green growth models would require a comprehensive parameterization, which is beyond the scope of this thesis. Instead, it will be examined how the regression curve contributes in the context of decoupling and the green growth / post-growth debate, and how planetary boundaries can mathematically be introduced into the model.

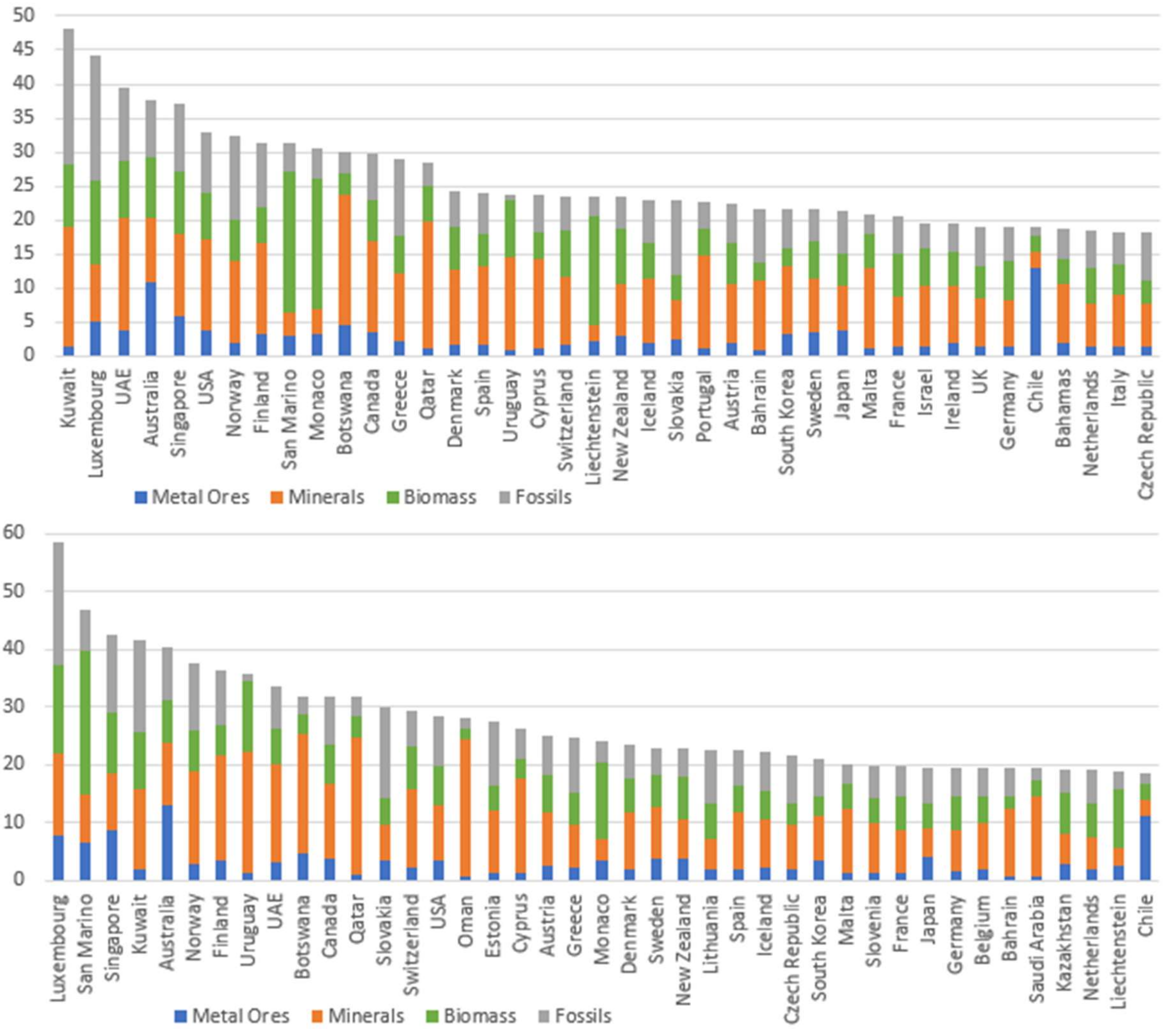
For the examination of hypothesis (5), an analysis of existing literature will be used to detect possible conflicts between SDG targets. Subsequently, a qualitative assessment of these conflicts will show to what extent the clusters and development patterns can be used for a prioritization among the SDG targets. Finally, further fields of application will be discussed.

3. Analysis

3.1. Footprint Analysis

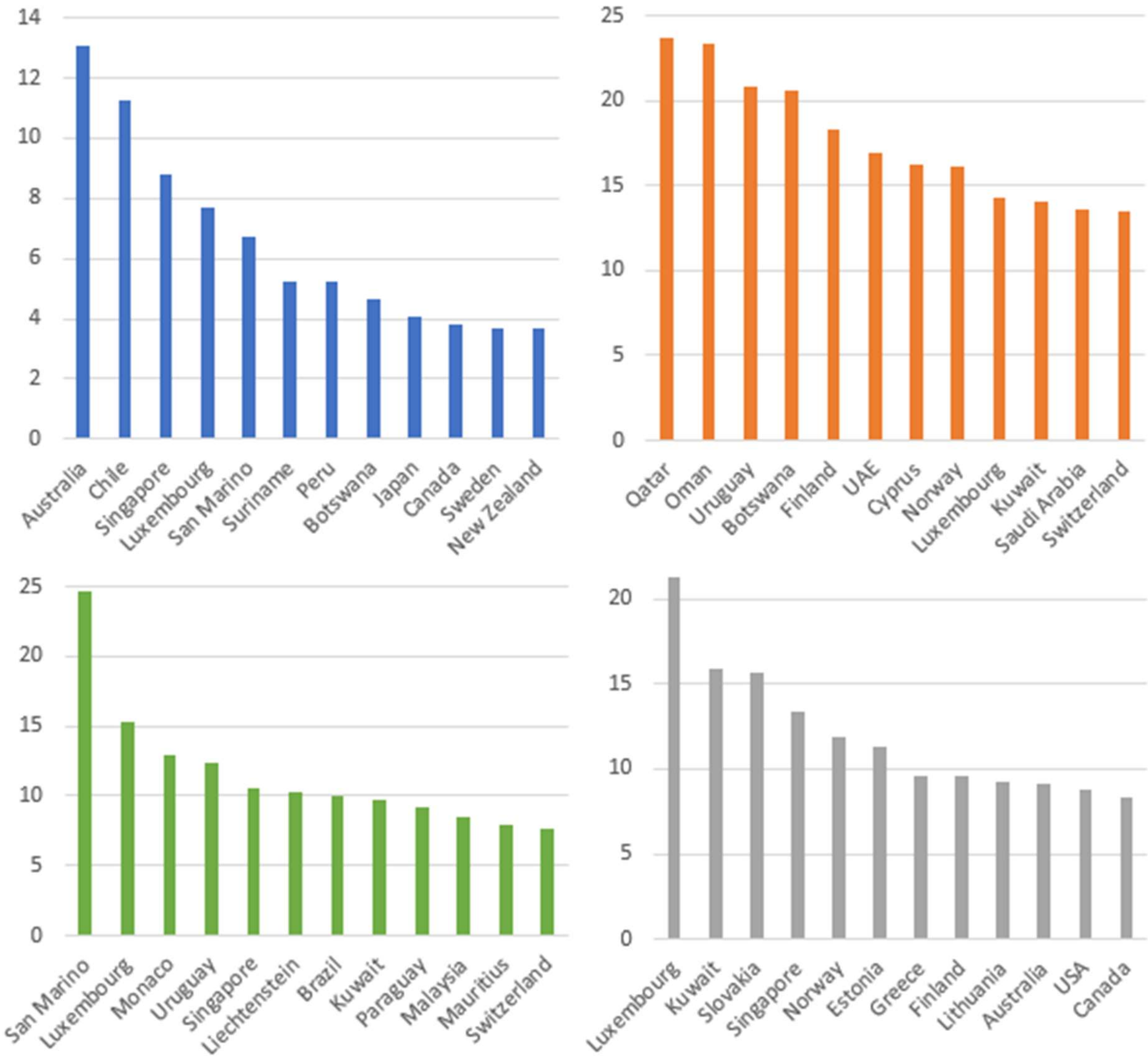
3.1.1. Material Footprints

Based on Eora data used in the SCP-HAT, material footprints for over 170 countries have been calculated. Figures 7a and 7b show the material footprint composition of the countries with the highest footprints per capita, subdivided into Metal Ores, Minerals, Biomass and Fossil Fuels, for the periods from 1996-2005 and 2006-2015. As it has already been shown in previous work (Cibulka 2017), the material footprints are generally dominated by fossil fuels and minerals, with fossils being the major energy source and minerals the basic raw material for construction activity. Accordingly, countries with a high per capita energy intensity and construction activity tend to have higher footprints, such as the Gulf States and Asian City States. Interestingly, the footprints of European Mini-States are, generally, in the same range; however, their MF composition is



Figures 7a, 7b: MF Composition in t/cap/y; 7a: MF>18, 1996-2005 avg; 7b: MF>18.5, 2006-2015 avg

dominated by biomass; this might result from resource intensive alimentation and the utilization of biomass as an alternative fuel.



Figures 8a: Metal Ores (upper left); 8b: Minerals (upper right); 8c: Biomass (bottom left); 8d: Fossil Fuels (bottom right); each Top 12 countries per MF type, in t/cap/y, 2006-2015 avg

Figures 8a-8d show the Top 12 countries of each group of material for the period 2006-2015. The highest metal ores footprints occur in countries with a high mining activity. This is remarkable, as the consumption of products containing metals is not known to be higher in mining countries, and might possibly result from methodological issues related to the attribution of residuals (which cannot be attributed to the final product), or data issues regarding the disaggregation of mining products. The same effect can be seen in the Biomass ranking, where, right after the European Mini-States, countries with a high biomass production like Uruguay, Brazil, Paraguay and Malaysia can be found in the Top 12. The minerals and fossils rankings are, on the contrary, dominated by countries with a high construction activity and a high energy demand.

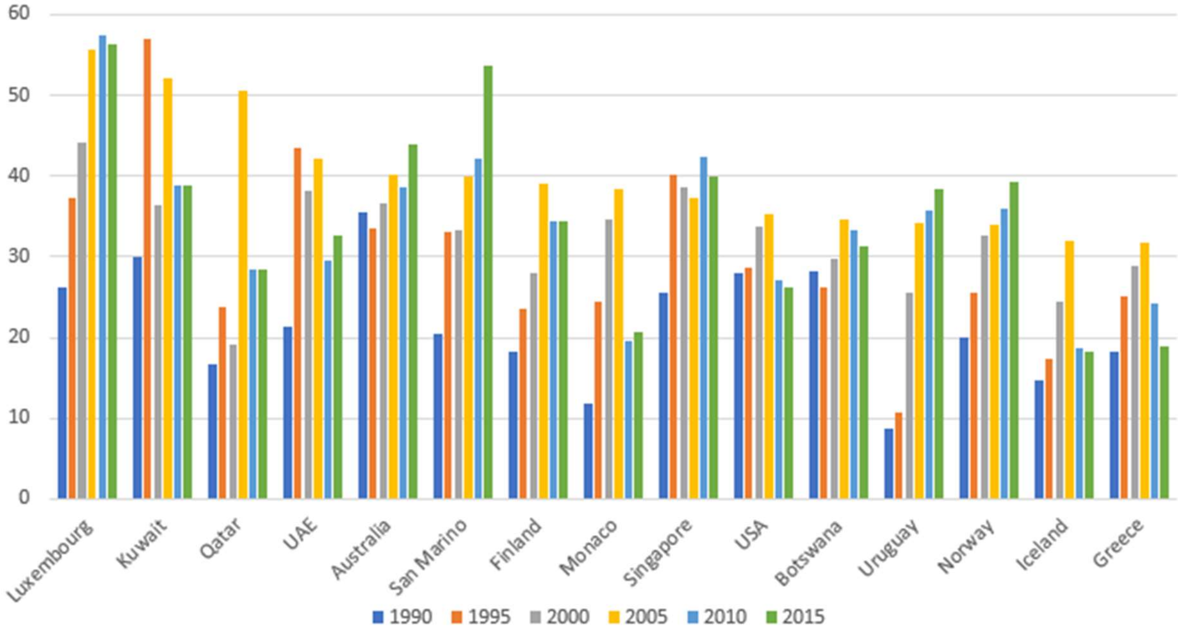


Figure 9: Material Footprint Development, t/cap/y, Top 15 countries (2005 ranking)

It is interesting to note that many countries with high minerals, biomass and fossil fuels footprints are not among the top nations of human development, indicating that these countries are currently catching up regarding their resource use (Uruguay, Botswana, Brazil, CEE countries like the Baltics and Slovakia – compare Figure 9, for detailed results see Annex 1, Sheet 2). Those countries, whose material footprints are particularly high and which are also highly developed, seem to be mainly small countries with a very high degree of urbanization, like San Marino, Luxembourg, Monaco, Qatar, UAE, Kuwait and Singapore, and countries with a traditionally high material use, like the US, Canada and Australia.

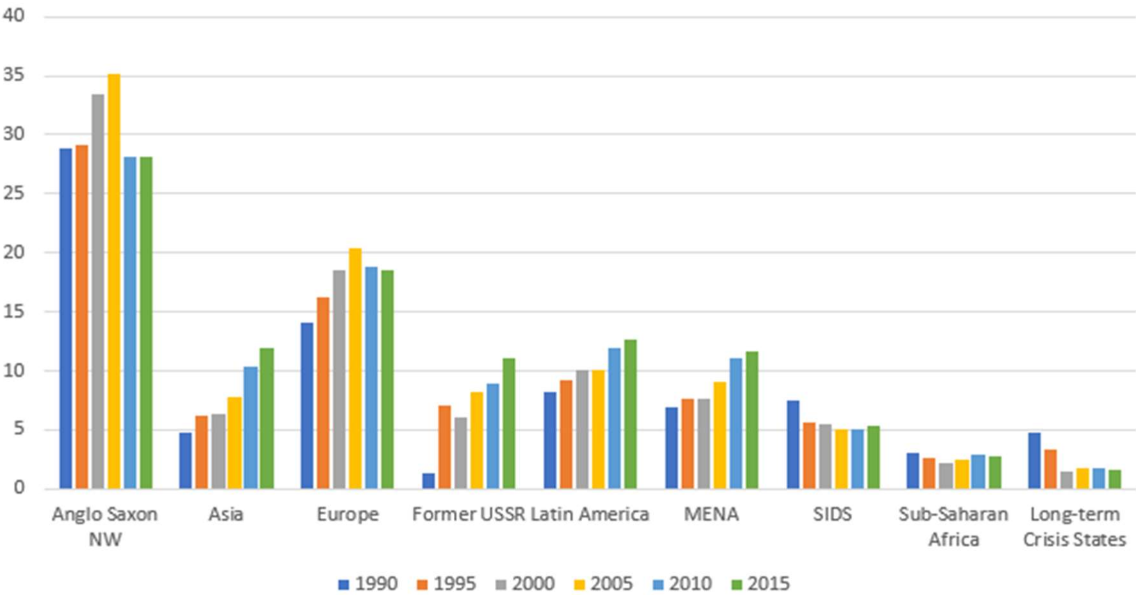
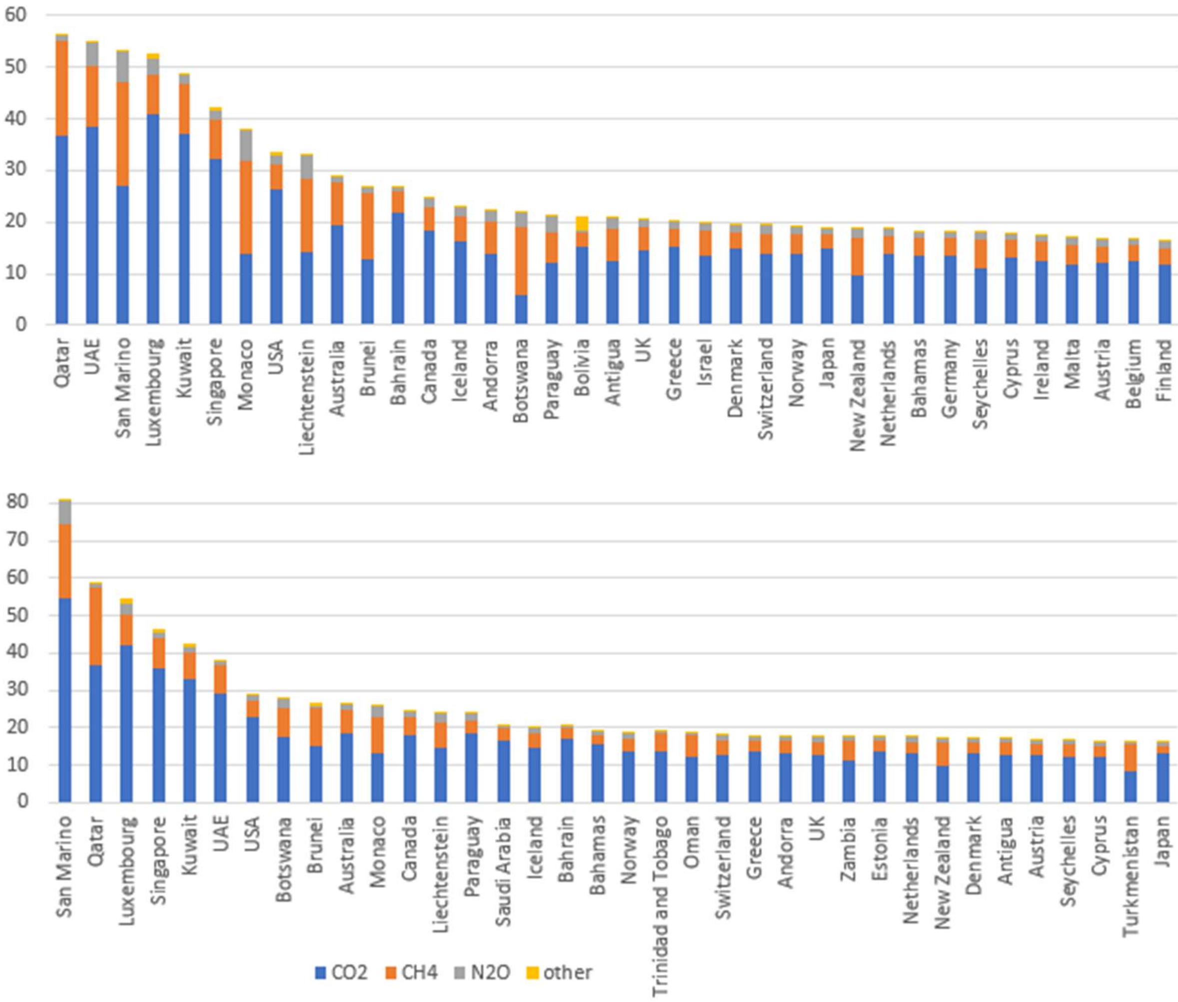


Figure 10: Material Footprint Development, t/cap/y, world regions

The same can be observed even better in the comparison of the world regions (Figure 10): While resource use per capita has dropped between 2005 and 2010 in the Anglo-Saxon New World and Europe, it has remained stable since. At the same time, Asia, the MENA region, the former USSR and Latin America are quickly catching up; Africa, Small Island Developing States (SIDS) and crisis states, however, are stagnating around or below five tons per capita and year.

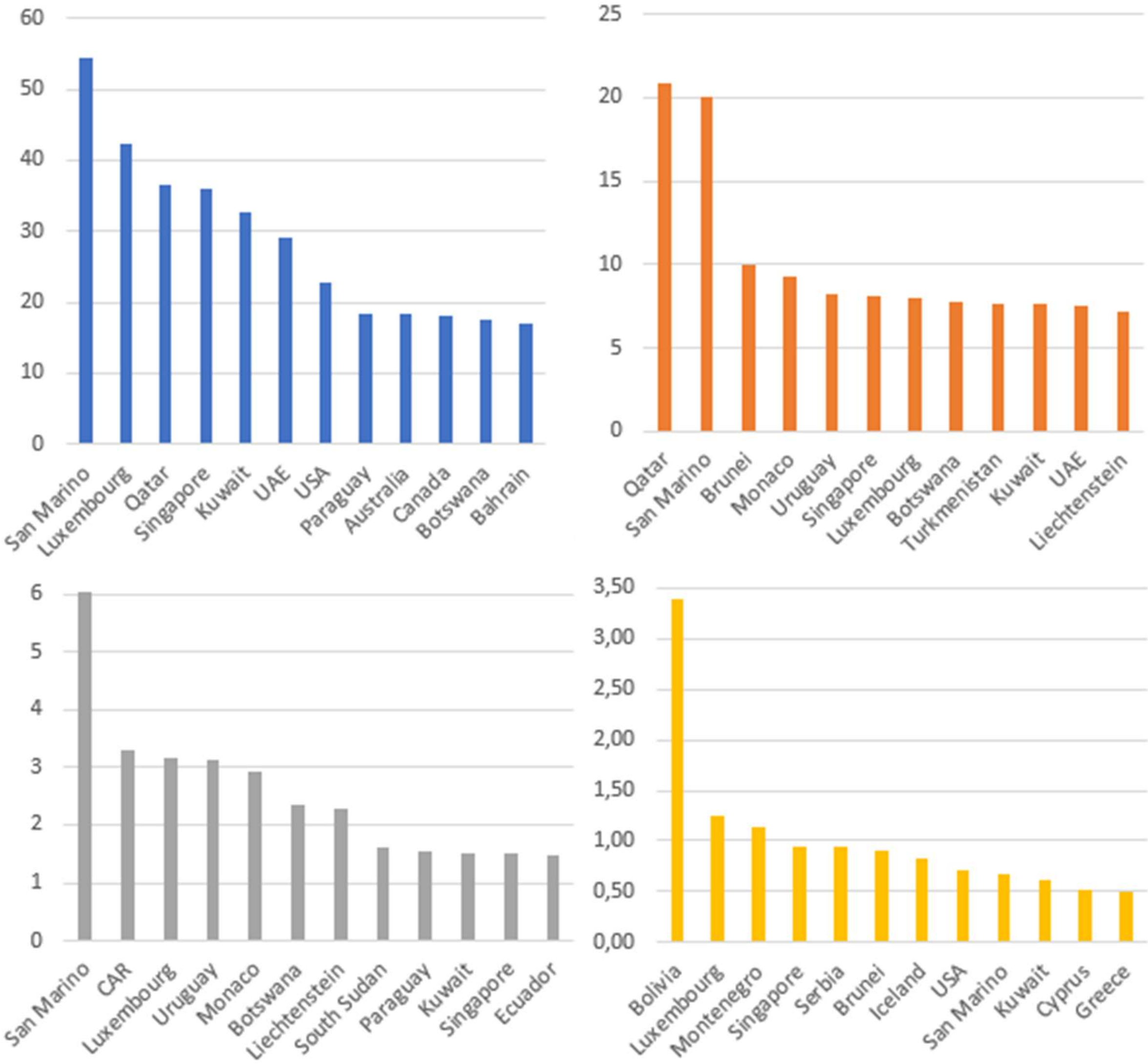
3.1.2. Carbon Footprints

Carbon footprints consist of the greenhouse gases (GHG) CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), PFCs (perfluorocarbons), HFCs (hydrofluorocarbons) and SF_6 (sulphur hexafluoride), and are expressed as CO_2-equivalents as explained in the annex of the technical report to the SCP-HAT (Schmelz, et al. 2018).



Figures 11a, 11b: Carbon Footprint Composition, >16t/cap/y; 11a: 1996-2005 avg; 11b: 2006-2015 avg

In both time frames (Figure 11), the compositions of the carbon footprints are dominated by CO_2, with varying proportions of the other GHGs. The highest carbon footprints per capita are, even more significantly than the material footprints, left by city states from Europe, East Asia and the Gulf States (also compare Figure 12a). Most of the countries in the range between 16 and 30 $tCO_2eq/y/cap$ are also highly developed countries; however, there are quite remarkable exceptions such as island states (Antigua, Bahamas, Trinidad, Seychelles), Botswana and Paraguay, which we know as resource intensive countries from the MFs, and Zambia.



Figures 12a: Carbon Dioxide (upper left); 12b: Methane (upper right); 12c: Nitrous oxide (bottom left); 12d: Other GHGs (bottom right); each Top 12 countries per CF type, in t/cap/y, 2006-2015 avg

The highest shares of CH_4 can generally be observed in European Mini-States and in natural gas producing countries (also compare Figure 12b); the former results most likely from the consumption of meat from ruminants, while the latter (compare Brunei, Turkmenistan) are very likely linked to escaping natural gas in the course of oil and gas production. The emission of N_2O is generally linked to agriculture (Figure 12c), resulting from the utilization of high amounts of nitrogen containing fertilizers. PFCs, HFCs and SF_6 (Figure 12d) are by-products from industrial processes. The Top 12 rankings of N_2O

and other GHGs show several outliers, such as the CAR, South Sudan, Ecuador and Bolivia, requiring further examination. The development of carbon footprints is similar to material footprints: The highest footprints can be found in small, urban countries, with quite some variation from year to year. The CFs of the rest of the Top 15 (all highly developed countries) are slowly declining (Figure 13).

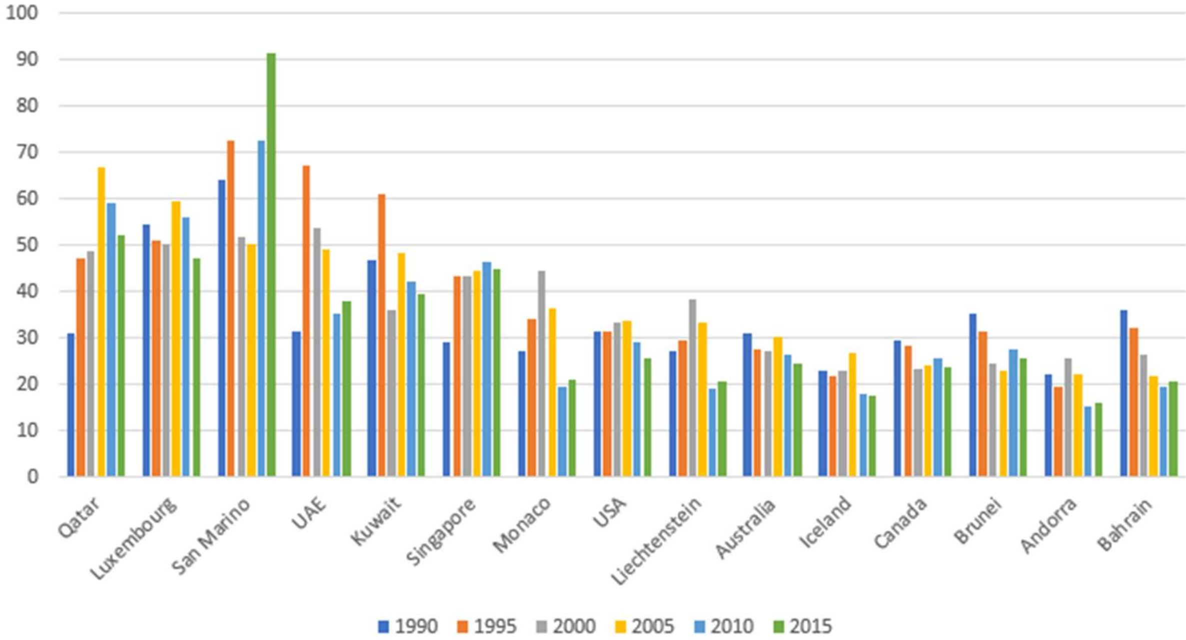


Figure 13: Carbon Footprint Development, t/cap/y, Top 15 countries (2005 ranking)

The same can be seen in Figure 14: The carbon footprint of the Anglo-Saxon New World and Europe is declining, that of Asia and the MENA regions catching up, while that of the former USSR plunged after 1990 and is slowly increasing since. The carbon footprint of Latin American countries and SIDS is constantly declining for 25 years; this is

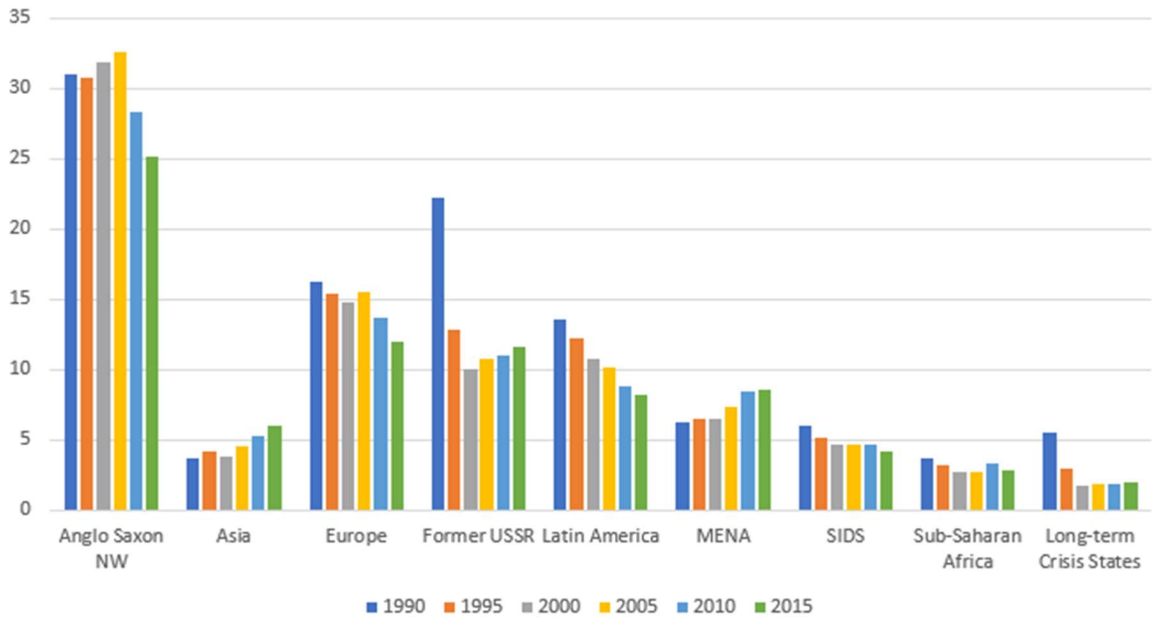
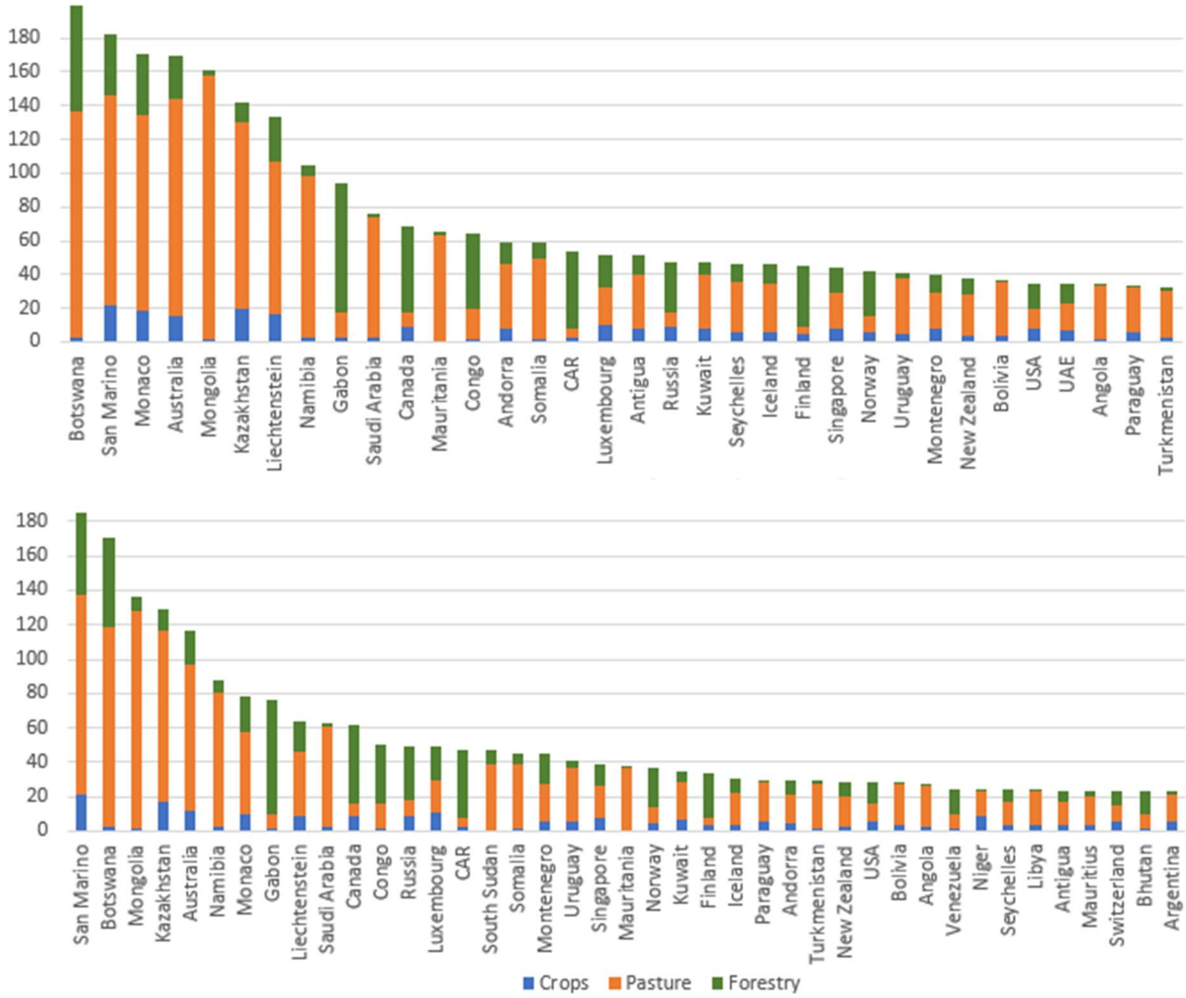


Figure 14: Carbon Footprint Development, t/cap/y, World Regions

surprising, insofar as many Latin American countries have enlarged their industry sectors, and forest fires have generally contributed to increasing CO_2 emissions.

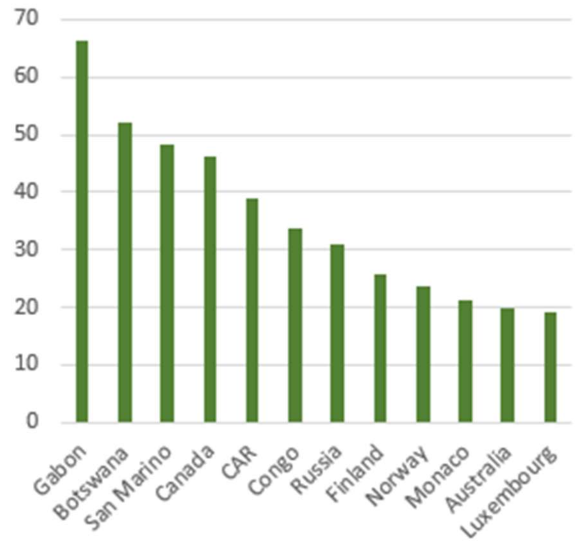
3.1.3. Land Footprints

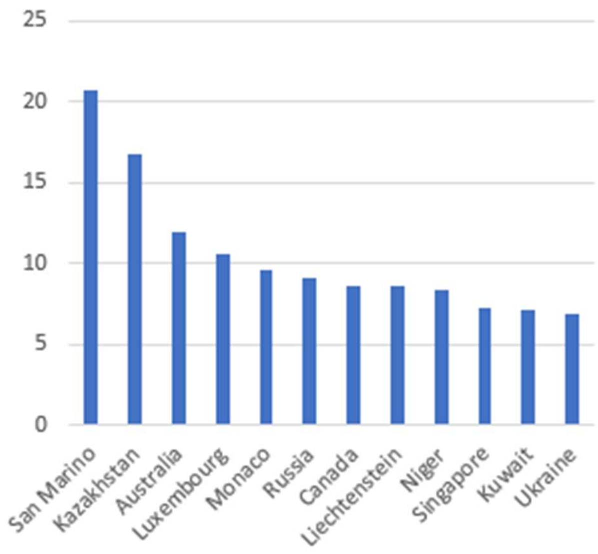
Unlike material and carbon footprints, the countries with the highest development do not automatically have the highest land footprints. On the contrary, apart from some city states, the land footprint ranking is led by countries large in area. The land footprint consists of crops, pasture and forestry; however, there is a very high variation in the footprint composition. It should be recalled that the data used in this analysis do not include different land productivities, but only the actual land areas.



Figures 15a, 15b: Land Footprint Composition, >22*1000m²/cap; 15a: 1996-2005 avg; 15b: 2006-2015 avg

As visible in Figure 15, the share of forestry in the footprint is mostly depending on the absolute share of forest in the country (see Gabon, Canada, CAR, Congo, Finland). The distinction between intensive and extensive forestry would be possible from the data, however, forestry as such seems to play a minor role in this thesis. Similar to biomass (see MF above), the crops footprint tends to be higher in highly developed countries,





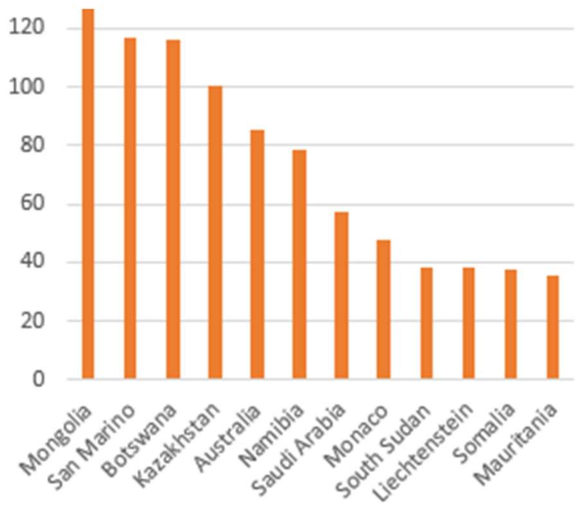


Figure 16a: Forestry (upper left);
Figure 16b: Crops (upper right);
Figure 16c: Pasture (left);
in 1000m²/cap, 2006-2015 avg

which may directly result from a higher per capita consumption, and in countries where the crops are grown. This refers to the same issue raised above, too. Pasture, in contrast, seems strongly linked to the conduct of land use. Most of the countries with high pasture footprints, like Mongolia, Botswana, Kazakhstan, Australia, Namibia, Saudi-Arabia, South Sudan, Somalia and Mauretania have a very low population density and a rather arid climate, allowing for extensive grazing and a nomadic conduct, therefore leading to a completely different utilization pattern.

Accordingly, the Top 15 countries all show a strong decline in land use per capita (Figure 17), which can mostly be explained by the increase in population density, leading to smaller grazing areas and more intensive land use, instead of a lower utilization of soil and land. The same can be seen in the comparison between world regions: All world regions show a decline in land use per capita (not in absolute terms; Figure 18), in particular the Anglo-Saxon New World and Sub-Saharan Africa.

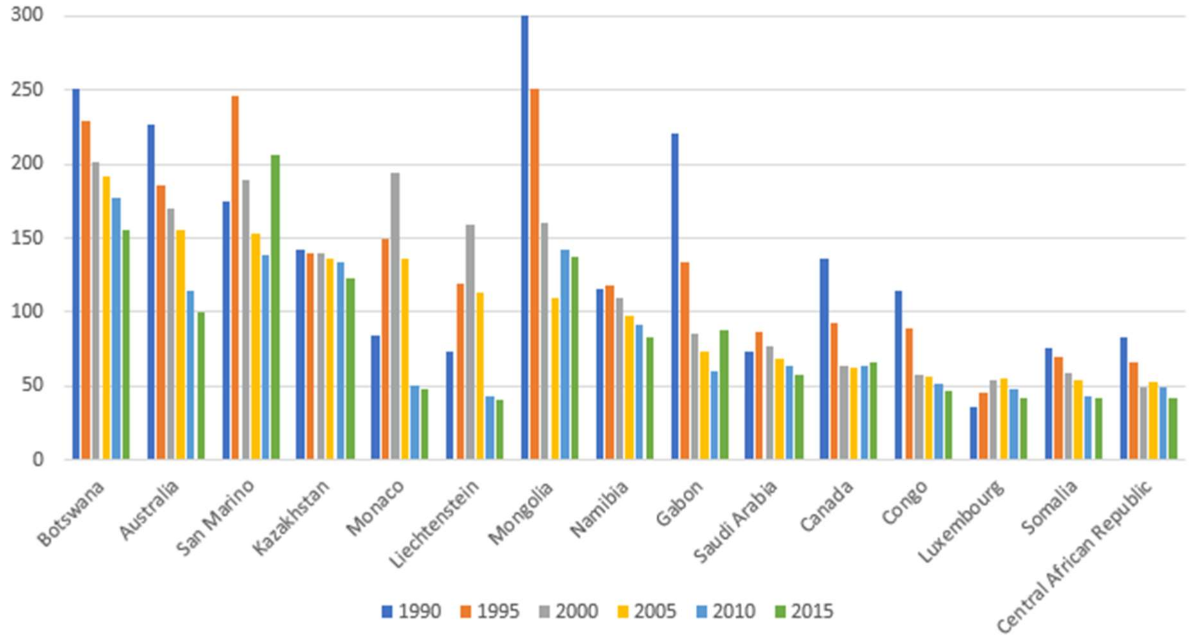


Figure 17: Land Footprint Development, 1000m²/cap, Top 15 countries (2005 ranking)

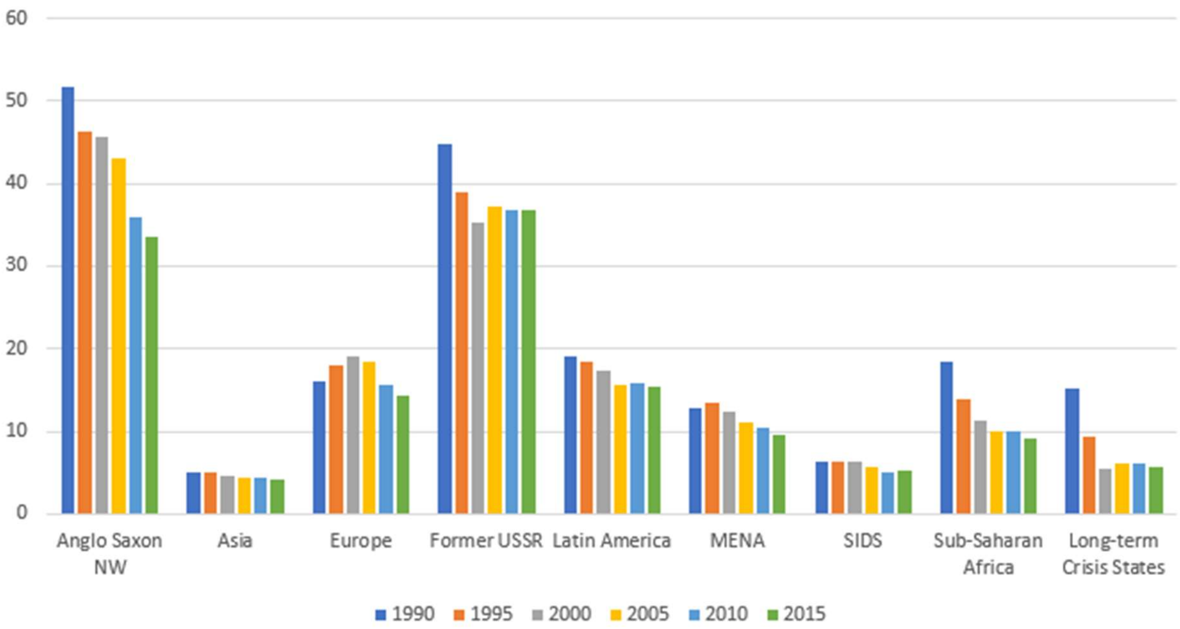


Figure 18: Land Footprint Development, 1000m²/cap, World Regions

3.1.4. Water Footprints

As explained in Section 2.2.6., water footprints consist of green water (rainwater), blue water (surface water) and grey water (water theoretically necessary for dilution of pollution). The overall WF composition is typically dominated by the sustainable green water (Figure 19).

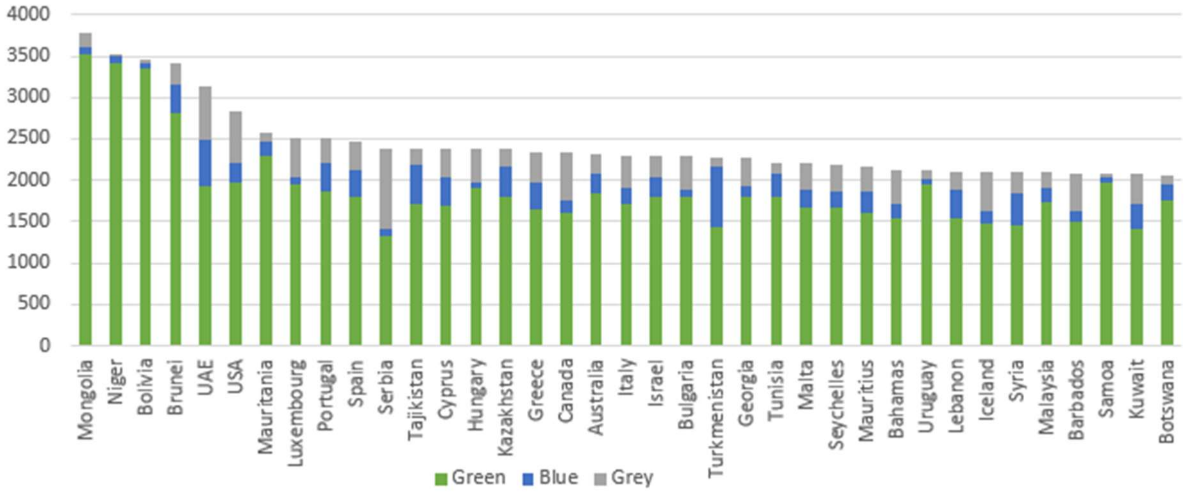


Figure 19: Water Footprint Composition, >2050m³/cap/y, 1996-2005 avg

However, blue and grey water footprint are much more relevant for the assessment of environmental pressures. Figure 20 shows all countries with a blue water footprint higher than 180m³/y/cap. Almost all of them are known to be affected by water scarcity or even drought, showing that the utilization of blue water is closely linked to the lack of green water. In contrast, the grey water footprints shown on top are highest in countries with a high level of industry (Gulf States, Southern Europe and in particular the USA).

Unfortunately, water footprint data are only available as an average for the timeframe 1996-2005, making an analysis of the development over time impossible.

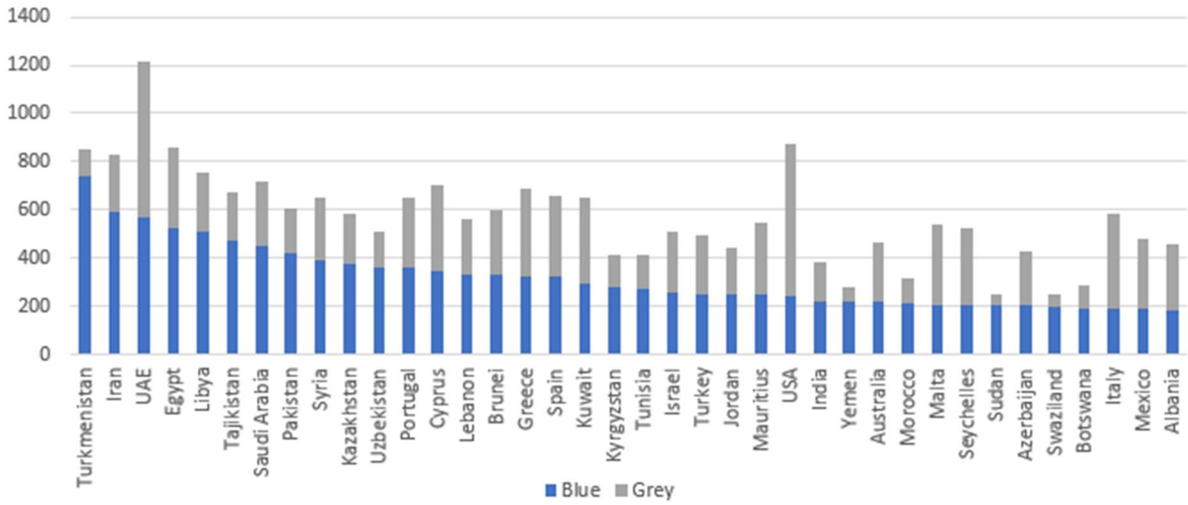


Figure 20: Blue and Grey Water Footprint Composition, >180m³BW/cap/y, 1996-2005 avg

3.2. Regression Analysis

3.2.1. Overall Regression Analysis

As the author has already shown in his previous thesis, indices measuring quality of life (like GDP, HDI, IHDI, Happiness indices) are not only strongly related with natural resource use; their relation can rather be described as a logarithmic curve, which means that the marginal utility of natural resource use declines with higher quality of life, i.e. it levels off.

In order to verify and further expand these results, another logarithmic regression was conducted via IBM SPSS Statistics. For this analysis, the HDI as a measure for quality of life is estimated as follows:

$HDI_{i,t} = Intercept + beta \ln (Footprint_{i,t}) + u_{i,t}$

For this calculation, the data of 173 countries (*i*) were used over a time period of 26 years (*t*, 1990-2015). Given some missing data (pairwise exclusion), the number of data cases is between 4000 and 4002. As Table 1 shows (compare Annex 2, Sheets 11, 13, 15), both MF, CF and LF can be well estimated via a logarithmic regression, with p-values smaller than .001.

Table 1: Logarithmic Regression, QL exby RFs (df = 1)	**Coefficients**		**R^2**	**N**	**F**	**p**
	B const.	*B var.*				
HDI explained by MF (overall)	0.383**	0.138**	.698	4000	9256	<.001
HDI explained by MF (96-05 avg)	0.439	0.108	.624	165		
HDI explained by MF (06-15 avg)	0.419	0.131	.728	168		
WHR explained by MF (06-15 avg)	3.955	0.710	.524	154		
HDI explained by CF (overall)	0.401**	0.130**	.590	4002	5756	<.001
HDI explained by CF (96-05 avg)	0.424	0.115	.612	165		
HDI explained by CF (06-15 avg)	0.457	0.125	.645	168		
WHR explained by CF (06-15 avg)	4.065	0.726	.492	154		
HDI explained by LF (overall)	0.512**	0.053**	.113	4002	510	<.001
HDI explained by LF (96-05 avg)	0.480	0.060	.177	165		
HDI explained by LF (06-15 avg)	0.539	0.062	.178	168		
WHR explained by LF (06-15 avg)	4.592	0.338	.128	154		

Table 1: Regression Analysis | see Annex 2 | in all cases: df=1 | * p<.01 | ** p<.001

The constant B-coefficient was calculated at 0.383 for the MF, at 0.401 for the CF and at 0.512 for the LF, the B-coefficient of the variable is 0.138 for the MF, 0.130 for the CF and 0.053 for the LF (all with $p<0.001$). The R^2-values vary between 0.698 (material footprint), 0.590 (carbon footprint) and 0.113 (land footprint), showing that the explanatory value of the carbon and material footprints on the HDI is very high, while the explanatory value of the LF on the HDI is smaller, but still quite considerable (population density is another important predictor between LFs and HDI, compare section 3.2.4.).

The rows in Table 1 with lighter background (1996-2005 and 2006-2015 averages) have been calculated via Microsoft Excel as regression lines in scatter charts, therefore the F and p-values are missing. Due to the averaged values, R^2-values are even higher than in the analysis including all values for 26 years, as the influence of outliers decreases; however, the explanatory value is high in either case. Interestingly, the intercept of the MF dropped by 0.02 between the two timeframes, while the intercepts of CF and LF rose by 0.03 and 0.06, respectively. An increase in intercept results in a shift of the curve to the upper left, and thus to – on average – lower resource use values per capita, while a lower intercept shows a shift to the lower right, showing an increase in average resource use per capita. Also, the variable coefficients show interesting differences; the closer the coefficient is to zero, the stronger is the levelling off effect of the logarithmic curve. We can see that for both MF and CF, the variable coefficient has risen, meaning that the – strong – levelling off effect has slightly decreased.

The Happiness Index is only available from 2005/2006, therefore, the timeframe 2006-2015 has been calculated to compare it with the HDI. As the maximum Happiness Index value is ten, all non-standardized values calculated have to be divided by ten for any comparison. Comparing Happiness for MF and CF, we can see that the R^2 values are slightly below (MF, CF) the explanatory values of the HDI, which is fully in line with the results presented in the previous thesis (Cibulka 2017). Furthermore, the intercepts are slightly lower (0.40 vs 0.42 and 0.41 vs 0.46, respectively, after dividing the happiness coefficient by ten), while the variable coefficients are clearly lower (0.071 vs 0.131 and 0.073 vs 0.125, respectively), compared to the HDI in the same timeframe.

After comparing the R^2-values and coefficients of HDI and Happiness, explained by the three resource footprints, the results of the previous thesis and the first hypothesis cannot be rejected that (1) there is a strong relation between quality of life and natural resource use, that (2) this relationship can be described by a logarithmic function, and that (3) this logarithmic function shifts parallelly over time – to the upper left if quality of life increases or resource use decreases, and to the lower right if the opposite is the case (this mechanism has already been shown in literature for energy footprints (Steinberger and Roberts 2010)).

Additionally, the author wants to point out that this relationship does not appear in the same way when analysing natural resource use and GHGs against the GDP. This relation has been found to be almost perfectly linear (Steinberger and Krausmann 2011), while other studies have found out that the relationship between GDP and HDI is, on their part, logarithmic (Knight and Rosa 2011). This results in the conclusion that if the position of a country in such a model using HDI and environmental footprint is shifted to the left, the GDP could slightly decrease at the same time, although quality of life remains the same or even increases. The author predicts from these results that in a regression comparing GDP, HDI and other quality of life indices with MF and CF as independent variable,

(1) the B-values of a linear regression (i.e. the slopes) are GDP > HDI/Happiness;

(2) the R^2 values of a linear regression are GDP > HDI/Happiness, of a logarithmic regression are HDI/Happiness > GDP;

(3) the R^2 values of HDI/Happiness are log > linear, of GDP/cap linear > log.

Variables (2006-2015 avg, prop. indexed to 1 for better visualization)	**Coefficients**		**R^2**	**N**
	B const.	*B var.*		
GDP PPP/cap explained by MF (linear)	0.0311	**0.0220**	**0.6028**	168
GDP PPP/cap explained by MF (log)	-0.0715	0.179	0.4271	168
HDI explained by MF (linear)	0.5453	**0.0119**	0.5755	168
HDI explained by MF (log)	0.4191	0.1308	**0.7278**	168
WHR explained by MF (linear)	0.4527	**0.0072**	0.5049	154
WHR explained by MF (log)	0.3955	0.0709	**0.5238**	154
GDP PPP/cap explained by CF (linear)	0.0343	**0.0260**	**0.7149**	168
GDP PPP/cap explained by CF (log)	-0.0701	0.197	0.4809	168
HDI explained by CF (linear)	0.5787	**0.0108**	0.4112	168
HDI explained by CF (log)	0.4586	0.125	**0.6453**	168
WHR explained by CF (linear)	0.4723	**0.0068**	0.3695	154
WHR explained by CF (log)	0.4065	0.073	**0.4919**	154

Table 2: Comparison of HDI, WHR, GDP PPP/cap | see Annex 1, Sheets 2, 3 | in all cases: df=1

Table 2 shows the results of this analysis, proofing all predictions right. The linear slopes of the GDP PPP/cap are higher than those of the HDI and Happiness Index (all as index to 1); all R^2 values of logarithmic regressions are higher for HDI and Happiness than for GDP PPP/cap; according to the R^2 values, the logarithmic regressions appears to be the better model for HDI and Happiness, and the linear regression the better model for the GDP PPP/cap. Figures 21a and 21b visualize this table as a scatter chart with linear and logarithmic regression lines.

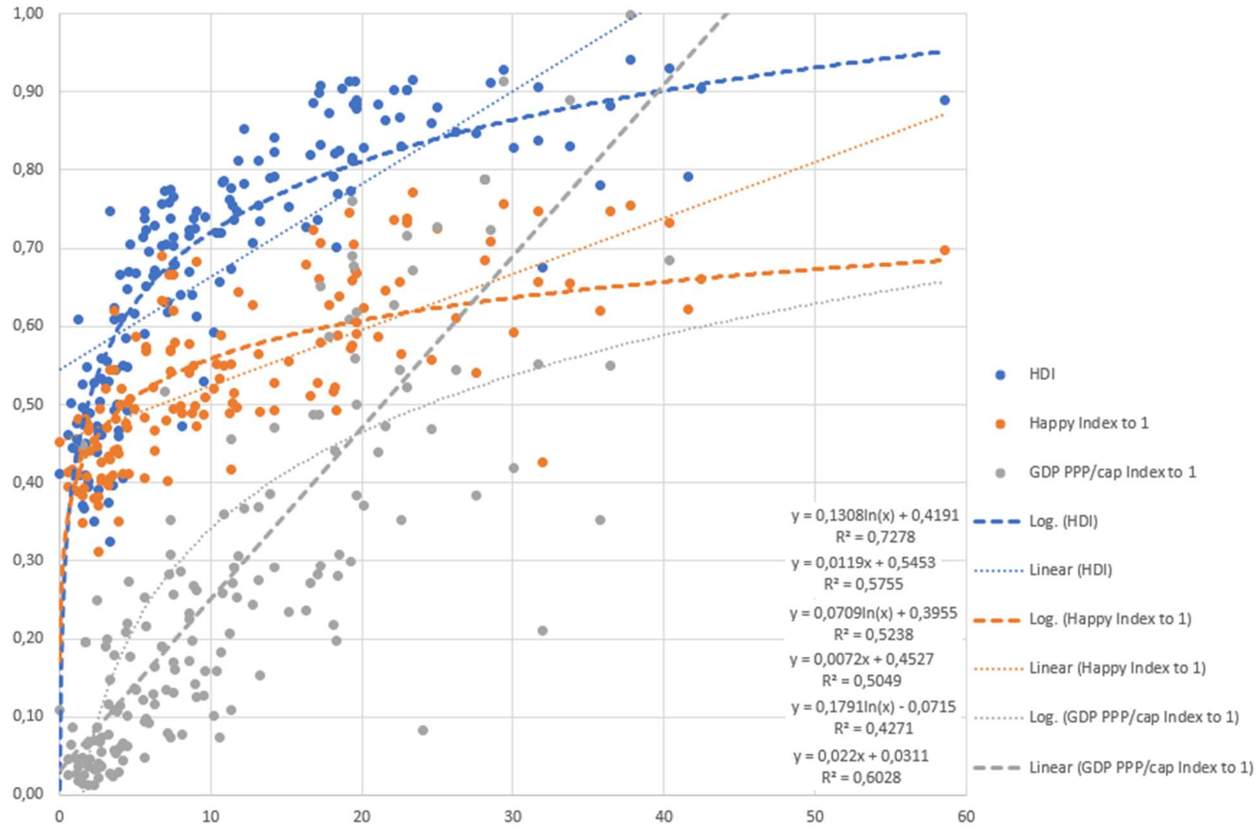


Figure 21a: GDP PPP/cap, HDI and Happiness Index, exby MF; 2006-2015 avg

Before continuing with a closer examination of the footprints, it is worth mentioning that the explanatory value is the same with switched dependent and independent variables, as long as there is only one predictor in the regression. This fact will be used in the following chapters to explain the footprints by the HDI, calculated via Microsoft Excel (scatter plots and exponential regression, due to the switched variables as the counter function of the logarithmic regression).[1] In the following chapters, the footprints will be subdivided into their components, that is Biomass, Metal Ores, Minerals and Fossil Fuels for the MF, carbon dioxide, methane, nitrous oxide and other GHGs for the CF, pasture, crops and

[1] Switching axes is necessary, as Microsoft Excel does only allow scatter and trendline analysis with one x-variable and many y-variables, but not the other way around.

forestry for the LF and blue, green and grey water for the WF. This analysis will show, which of the natural resources can reasonably been added to a model based on the overall regression results, and which resources should rather be treated separately.

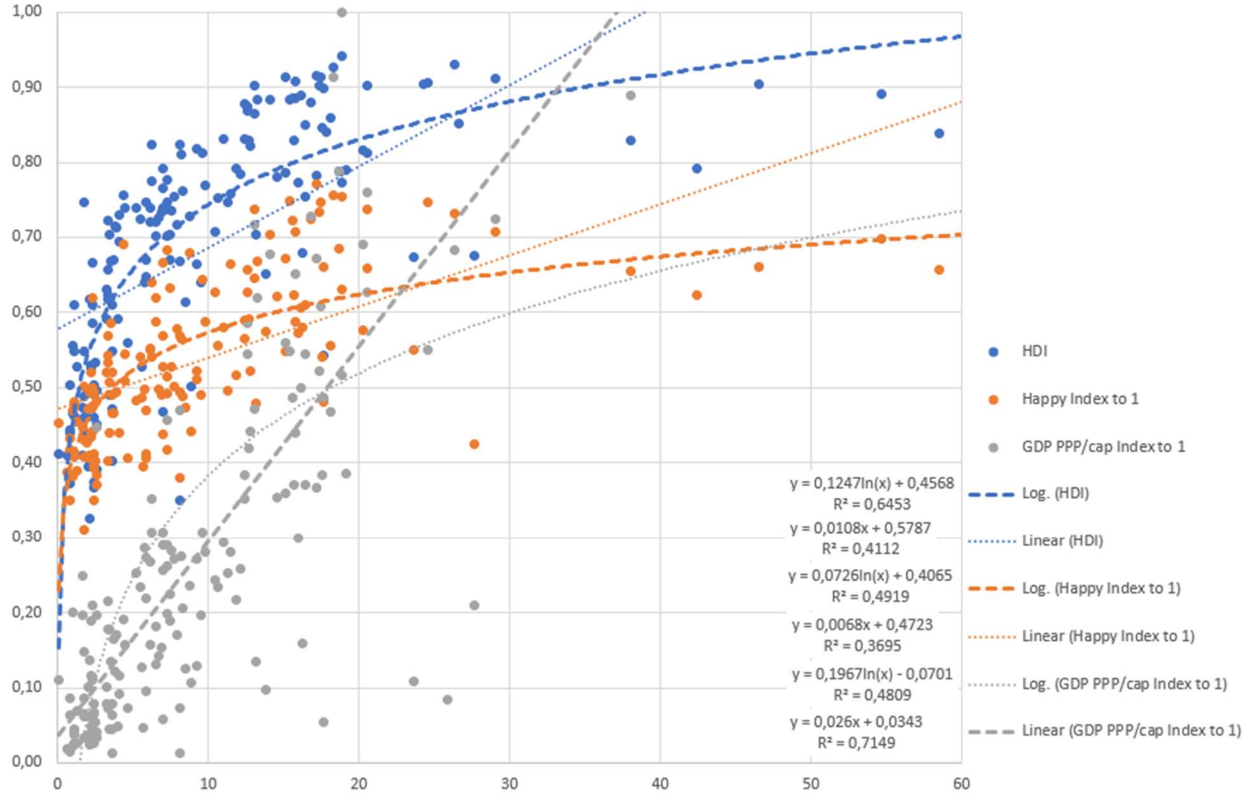
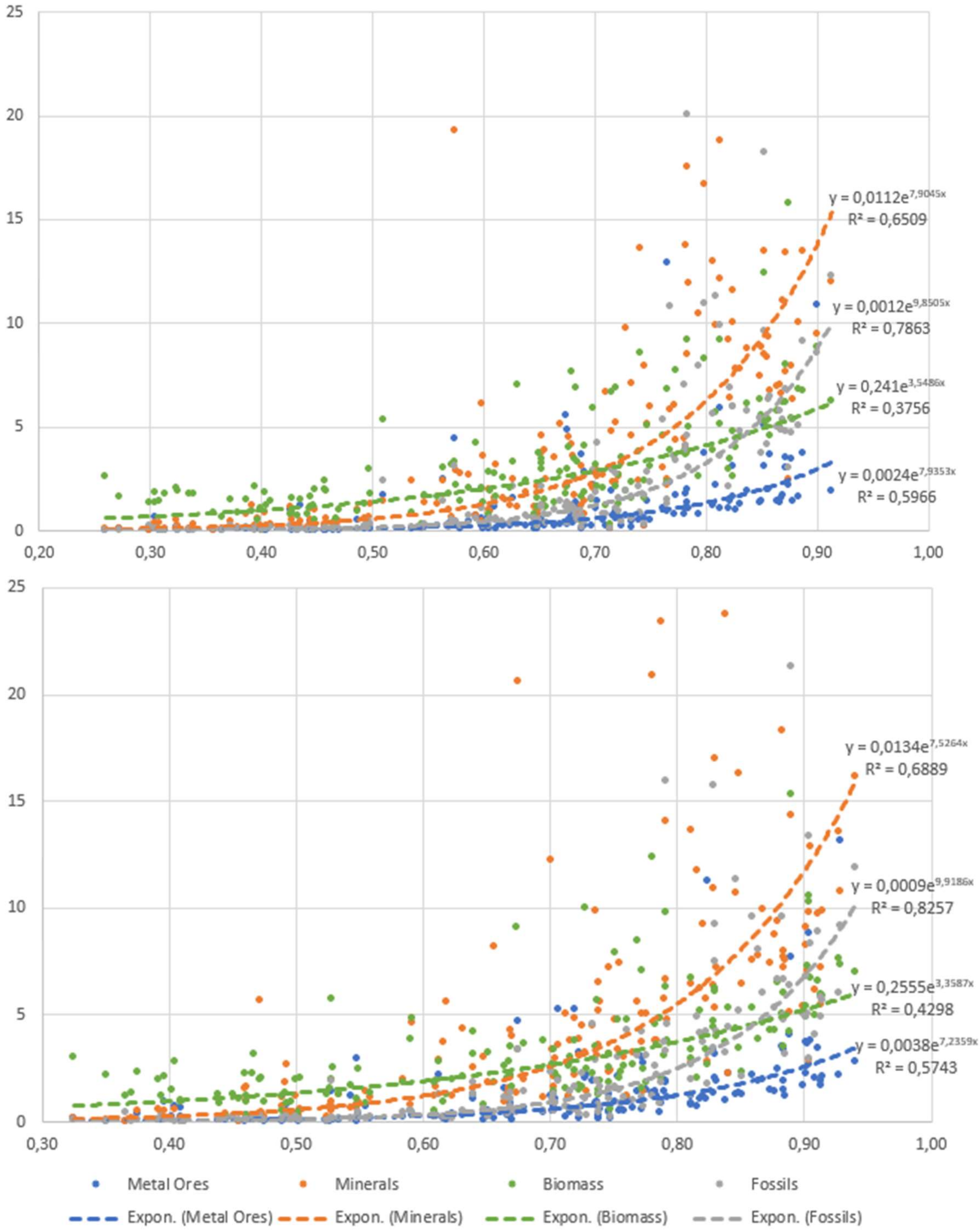


Figure 21b: GDP PPP/cap, HDI and Happiness Index, exby CMF; 2006-2015 avg

3.2.2. Detailed Analysis of Material Footprints vs HDI

Figures 22a and 22b show the scatter chart and the exponential regression lines of the four components of the MF, biomass, metal ores, minerals and fossil fuels, explained by the HDI, for the periods 1996-2005 and 2006-2015. In both periods, fossil fuels show the curve with the highest acceleration with rising HDI (see coefficient in the exponent), a value that remains roughly the same comparing the two periods. Also, the explanatory value of the HDI on fossil fuels is extremely high, with an R^2 of 0.786 and even 0.826, respectively. Minerals show the highest absolute values (compare the results of the footprint composition analysis in the previous chapter), also showing a very steep increase and a very high explanatory value of 0.651 for 1996-2005 and 0.689 for 2006-2015. Metal ores show a similar acceleration with rising HDI, but lower absolute values; the exponential curve does also very well explain metal ores, with R^2 values of 0.597 and 0.574, in spite of the outliers in the mid-HDI range. Biomass shows the least acceleration, with quite many outliers in the mid-HDI range it reaches R^2 values of 0.376 and 0.430. It



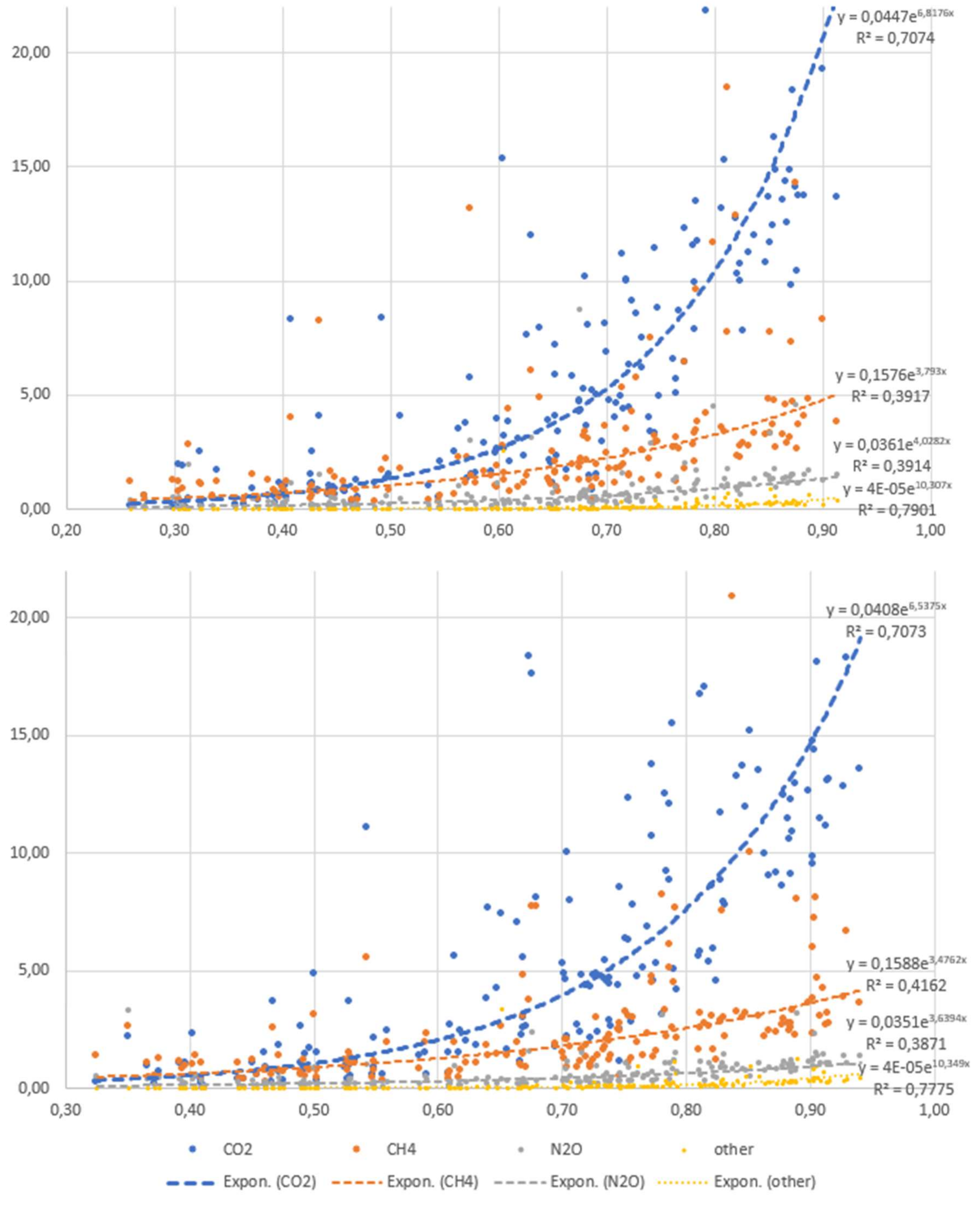
Figures 22a, 22b: MF Components (in t/cap/y) explained by HDI;
1996-2005 avg (Figure 22a, above); 2006-2015 avg (Figure 22b, below)

is interesting to note that the acceleration of the regression curves has slightly decreased for minerals, biomass and metal ores, but not fossil fuels, while the explanatory value has increased for minerals, fossils and biomass, but not metal ores.

To sum up the results of the analysis of material footprint components explained by HDI, all four components show a strong acceleration with higher HDI and a high explanatory value of the exponential regression curve. Therefore, all four components can be included in the model set out in the previous chapter.

3.2.3. Detailed Analysis of Carbon Footprints vs HDI

Figures 23a and 23b show the scatter chart and the exponential regression lines of the components of the carbon footprint, CO_2, CH_4 and N_2O, PFCs, HFCs and SF_6 have been aggregated to "other GHGs", explained by the HDI, for the periods 1996-2005 and 2006-



Figures 23a, 23b: CF Components (in t/cap/y) explained by HDI; 23a: 1996-2005 avg; 23b: 2006-2015 avg

2015. Although their absolute amount is rather small, other GHGs show the highest acceleration of the exponential regression curve with higher HDI (see coefficient in the exponent), and a very high explanatory value of 0.790 and 0.778, for the two periods, respectively. CO_2, with the by far highest absolute values, also shows a high acceleration with higher HDI, and also very high explanatory values of 0.707 for both periods.

Methane and nitrous oxide, on the other hand, show a lower acceleration with higher HDI, and quite a few outliers in the mid-HDI range, leading to explanatory values of around 0.4, which may result from the nature of CH_4 and N_2O, as emitted mostly by ruminants, unflared gas from crude oil production, and agriculture. Although this value is smaller than that of CO_2 and other GHGs, the logarithmic regression has still high explanatory value for all greenhouse gases, and all components of the carbon footprint can be used in the overall model.

3.2.4. Detailed Analysis of Land Footprints vs HDI and Population Density

In contrast to the MF and the CF, the land footprint and its components can be explained by the HDI to a lesser extent. Figures 24a and 24b show the scatter chart and the exponential regression lines of the components of the land footprint, crops, pasture and forestry, for the periods 1996-2005 and 2006-2015. The charts use a logarithmic scale on the y-axis; hence, the exponential regression lines appear straight. The results show that

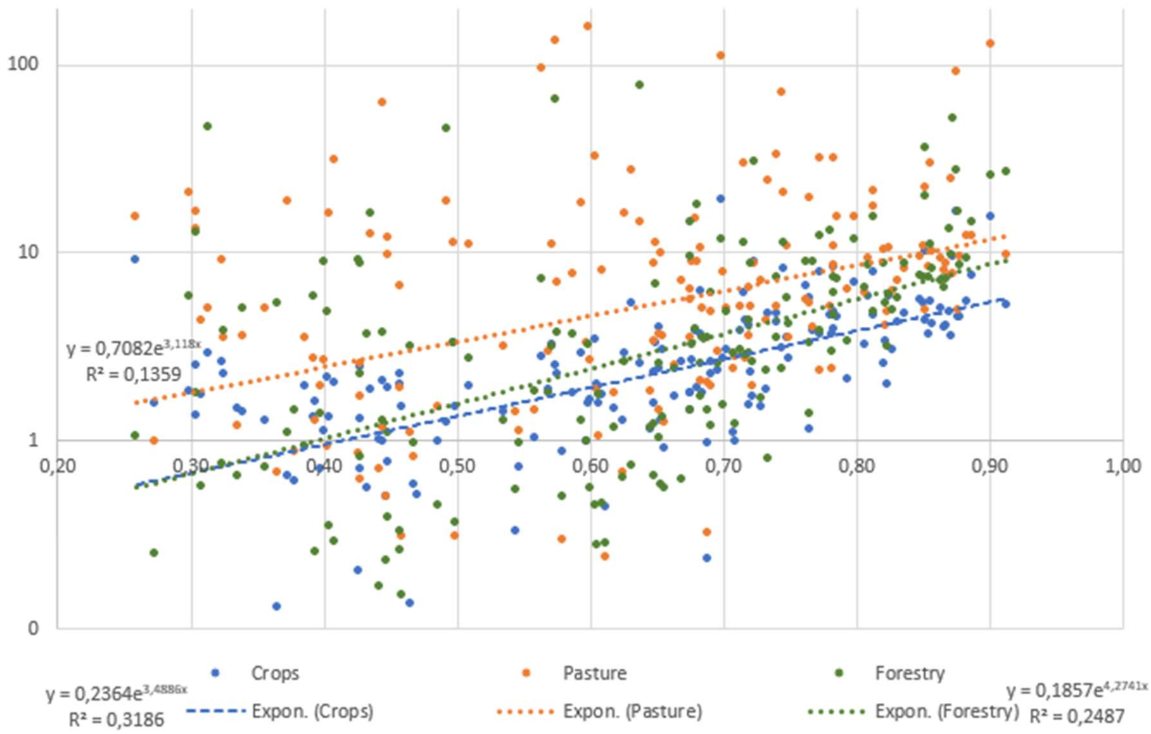


Figure 24a: LF Components in 1000m²/cap explained by HDI; 1996-2005 avg

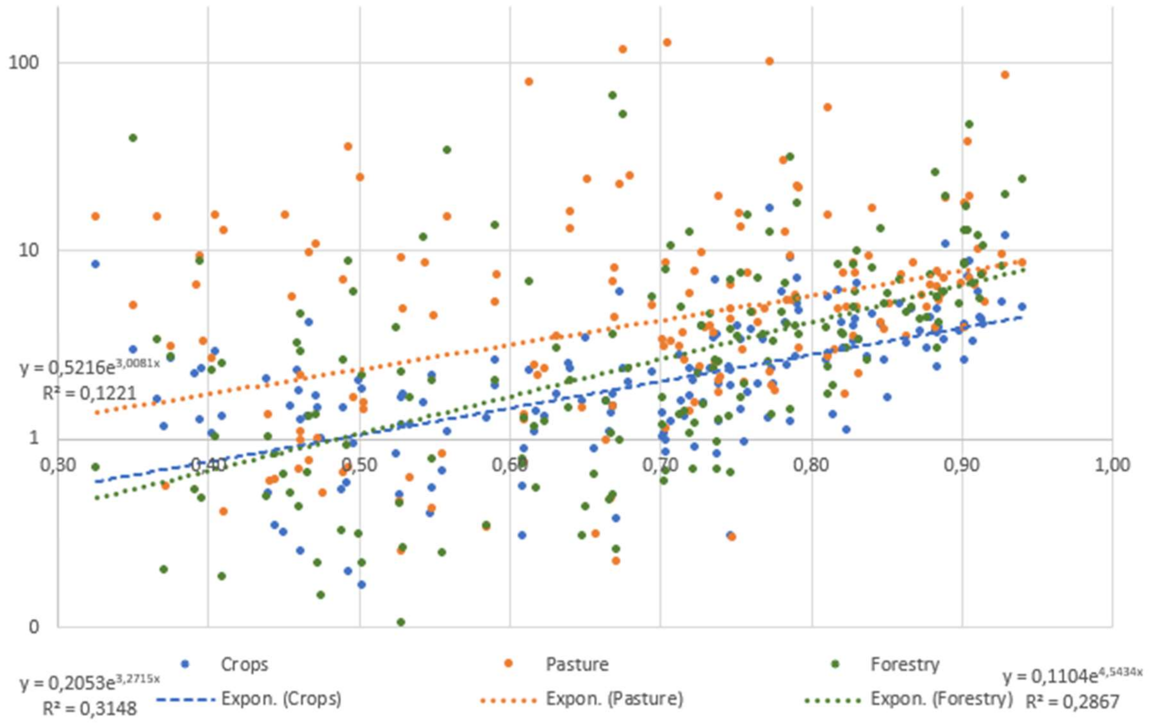


Figure 24b: LF Components in 1000m²/cap explained by HDI; 2006-2015 avg

both crops and forestry show a medium explanatory value. Crops show a stable R^2 value of around 0.31 for both periods, while it had increased from 0.2487 to 0.2867 between the periods for forestry, with forestry having the stronger acceleration with higher HDI. Pasture, as the dominating component in absolute terms (in m²/cap), has the lowest dependence on the HDI, with a weaker acceleration and numerous outliers in both the low-HDI and mid-HDI range, leading to R^2-values of 0.1221 and 0.1359, respectively. From these results it appears, as if there could be other variables next to human development explaining these land use footprint components.

Population density is, next to land productivity, a variable which could possibly be suitable to complement the HDI in that regard, is. Indeed, a negative logarithmic regression reaches quite considerable results for crops and forestry (Figure 25, period 2006-2015; R^2 crops: 0.3037; R^2 forestry: 0.1564). With the statistical means used, pasture can be described best as a polynomic function of 6th degree; however, experiments using *wolframalpha.com* indicate that there are actually two functions to be added, one negative logarithmic function and one exponential function (with a very low multiplicator).

The negative logarithmic function, explaining land footprints by population density, makes perfectly sense, as the per capita footprint does necessarily decline, if the number

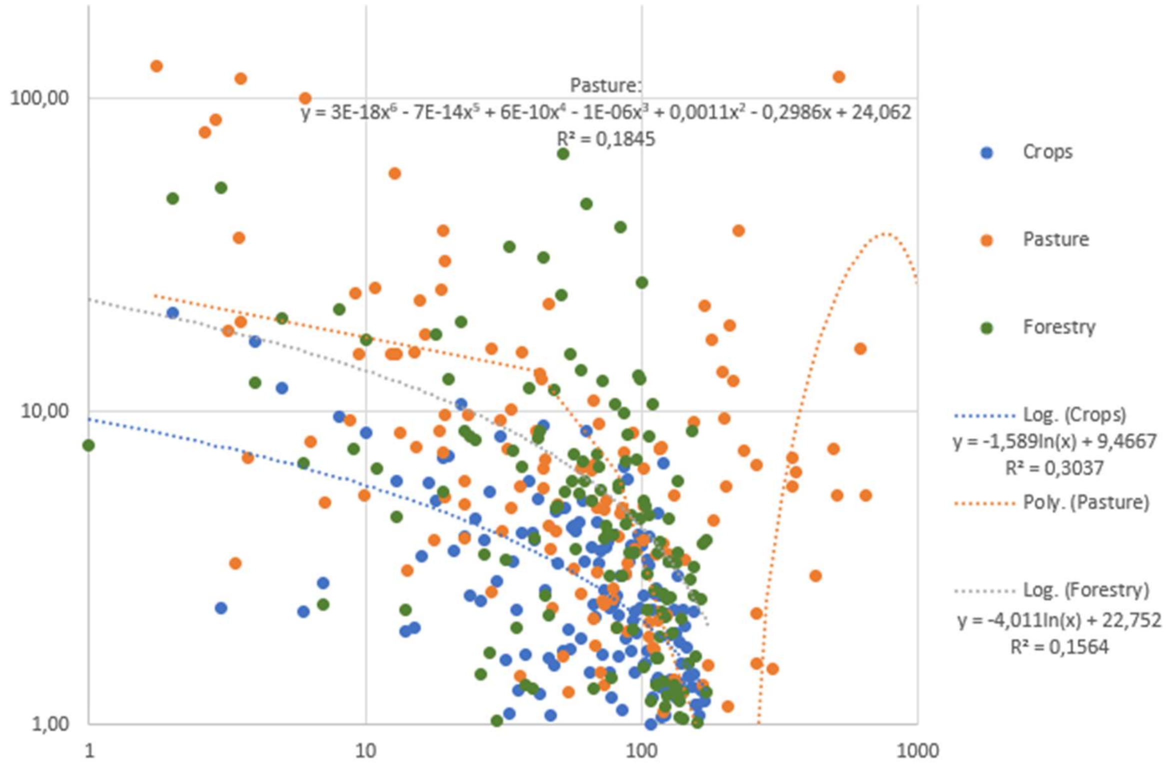


Figure 25: LF Components in 1000m²/cap, explained by Population Density, 2006-2015 avg

of inhabitants increases and the factor described (in this case, land area) remains more or less constant. In this sense it is also clear that countries with a large area and small population densities reach high land footprints, in particular those (mostly arid and semi-arid) countries, where (semi-)nomadic pasture is the predominant economic sector. The strong acceleration of pasture footprints on the other side of the chart (Figure 25), can be explained by the meat consumption in highly urbanized (high population density) countries.

To sum up, the land footprint cannot be as well explained by the HDI as material and carbon footprints. However, it is interesting that at least crops can be still somewhat well explained by the exponential regression line using the HDI as a predictor, making it possible to use it in the overall model in a qualified sense. For future research, further subdividing land use according to intensity could lead to interesting results. The issue of population density as a factor reducing resource use per capita (but of course not reducing the absolute pressure on the planet) will be discussed in Section 4.1.

3.2.5. Detailed Analysis of Water Footprints vs HDI

Figures 26 shows the scatter chart and the exponential regression lines of two components of the water footprint, blue water and grey water, for the periods 1996-2005. Green water has not been included, first, because of its minor role in the context of resource depletion, and second, because to its high absolute values it would diminish the illustrative effect of the chart. The chart shows that blue water footprints cannot be explained by the HDI through an exponential function; also alternative approaches do not result in high explanatory values (see for a negative polynomic function of 2nd degree: R^2=0.0328). This can be explained by the fact that blue water footprints are rather triggered by green water scarcity.

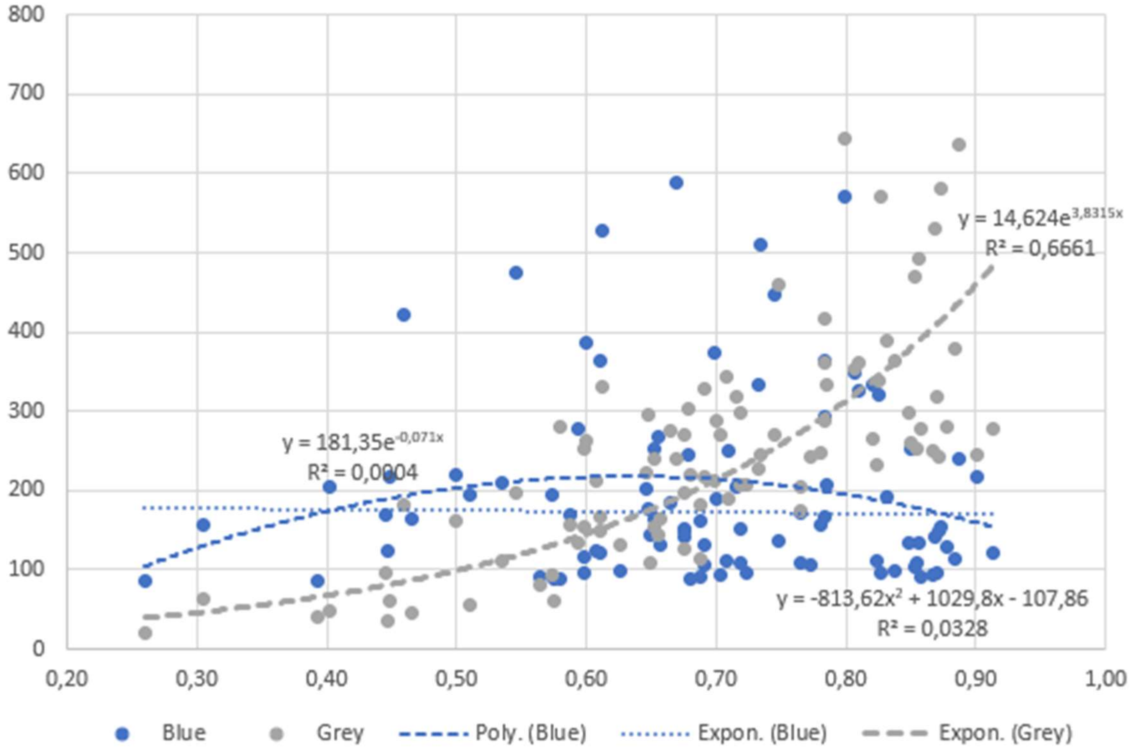


Figure 26: WF Composition in m^3/cap/y, explained by HDI, 1996-2005 avg

Grey water, in contrast, shows a strong acceleration with increasing HDI, and the exponential regression line reaches an R^2 value of 0.6661, which is in the same range as the material and carbon footprints. To sum up, the water footprint components green water and blue water cannot be taken into consideration, while the grey water footprint should be added to the overall model set up in this thesis. This does not mean that the green and blue water footprints are to be ignored; on the contrary, particularly blue water plays an incredibly important role when it comes to sustainable resource use and, therefore, sustainable consumption. Accordingly, the countries showing a high blue water footprint should also be thematized, when it comes to the prioritization of SDG implementation, CDM measures and environmental investments (compare Section 4.2.).

3.3. Timeline Analysis

In this chapter, scatter charts of HDI explained by environmental footprints are used to depict timelines from 1990 to 2015, with five-year intervals. As a chart including all countries would be too unclear and indistinct, countries have been grouped to world regions and sub-regions, with the sub-regions being both geographically and economically similar enough to achieve meaningful results. The regions are: Anglo-Saxon New World,[2] Europe,[3] Asia,[4] former USSR,[5] MENA-region,[6] Latin America,[7] Sub-Saharan Africa,[8] Small Island Developing States.[9] For setting up the regions, the HDIs have been calculated as weighed average, weighed with the population size. Unavailable data cases have been subject to pairwise exclusion.

3.3.1. Timelines of Material Footprints vs HDI

As one could expect from the analysis of footprints per capita and the regression analysis, the overall shape of development follows a logarithmic curve (Figure 27). The highest material footprints, together with a high development, can be found in European Mini-States, Asian City States and in the Anglo-Saxon New World. An even higher development, but much smaller material footprints occur in all other European sub-regions, Japan and Korea, and Israel. All European and Anglo-Saxon countries show a remarkable pattern: around 2005, their development timeline changes direction, and maintains an increase in HDI while resource use is declining. However, this development was particularly strong between 2005 and 2010, when the financial crisis occurred. Thereafter, both HDI and MF remained roughly the same.

---

[2] USA, Canada, Australia & Neu Zealand
[3] North & Central, Scandinavia, British Islands, Mediterranean, SEE, CEE, Mini-States
[4] JPN/KOR, China, City States, Indochina, MAL/IDN/PHI, India, Rest of Indian Subcontinent
[5] Russia, Eastern Europe (Ukraine, Belarus, Moldova), Caucasus, Central Asia
[6] Maghreb, Egypt, Mashrik, Gulf States (incl. Saudi Arabia), Turkey, Israel, Iran
[7] Mexico, Middle America, Gran Colombia (Colombia, Ecuador, Venezuela, Suriname), Andes (Peru, Bolivia, Chile), MERCOSUR (Brazil, Argentina, Paraguay, Uruguay)
[8] Western Africa, Eastern Africa (incl Madagascar), Horn of Africa, Northern Central (Chad, Sudan, South Sudan, CAR, Cameroon), Southern Central (Gabon, Congo, Congo DR, Angola, Zambia), Southern (Namibia, Botswana, Swaziland, Lesotho), RSA
[9] Caribbean (Great and Small Antilles), Pacific, Atlantic & Indian Ocean

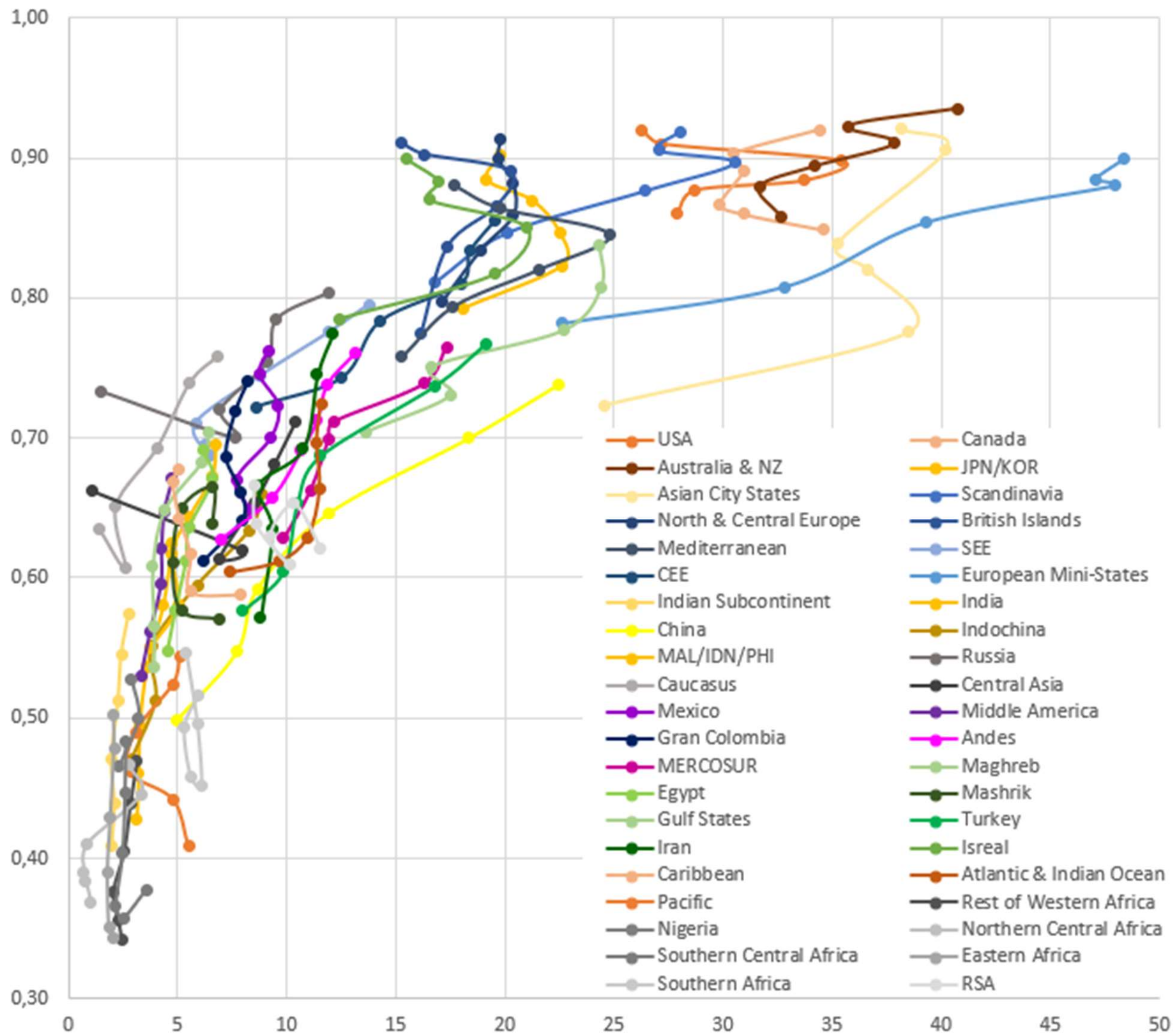


Figure 27: HDI explained by MF; timeline analysis of sub-regions, 1990-2015, 5-year intervals

The former USSR countries show, again, a very special pattern; resource use has dropped significantly shortly before 1990 and occurs close to zero at that time. While resource use increases in the following, the HDI still declines until between 1995 and 2000. Since, both HDI and material footprint are rising linearly, with wide differences between the sub-regions: Caucasus remains left of the overall curve, with a stronger increase in HDI than in MF. Central Asia, in contrast, has crossed the overall curve and is now using more raw materials per capita than a regression line would predict. The MENA region shows very different patterns; while the Gulf States are clearly at the lower right of the curve (higher MF, comparatively lower HDI), most other parts of the region are very close to the overall pattern. This is in line with the observation made with City States: The strong acceleration is driven by urbanization and consumption patterns of rising elites.

This might also be the reason, why China can be found at the lower right of the curve, having caught up with many of the European countries in recent year when it comes to the footprint, but not with regards to HDI. Most of the Asian and Latin American sub-regions are found very close to the overall pattern. The timelines of Small Island Developing States and African countries are difficult to interpret, as data availability is poor, and the exact position of the scatter could be influenced by the selection of countries available. However, it can be seen that Southern Africa and the RSA countries are clearly at the right of the curve.

Altogether, while the overall pattern follows a logarithmic curve, there are two major observations to add: (1) actual points of turnaround have already occurred, however, the countries concerned do now rather stagnate; (2) the timelines of sub-regions, as well as of large countries considered separately, are not constantly moving along the line, but rather in steps of acceleration and deceleration. It would be a worthwhile question for further research, how these steps are triggered; supposedly, accelerations at lower HDIs are triggered by an increasing private consumption of products from resource-intensive industries, while accelerations at higher GDPs are resulting from urbanization and elitist lifestyle. Decelerations would rather result from an increasing focus on services that are less resource intensive, and in particular consumption patterns, circularity and resource-efficiency (technical progress).

3.3.2. Timelines of Carbon Footprints vs HDI

As the timelines of carbon footprints are very similar to the material footprints, only the difference will be explained in detail. In Figure 28 it can be seen that, again, European and Asian City States have the highest CF, followed by Anglo-Saxon countries and Gulf States (the latter having a lower HDI). Again, the former USSR countries show a very special pattern, and most of the Asian, Latin American and MENA countries are close to the overall curve.

The major differences are that the points of actual turnaround in developed countries are much more distinct, and that the development of CF reduction does not stagnate as much as the respective MF reduction. Moreover, many sub-regions with medium HDI already show a trend towards higher development with lower CF, particularly Mexico, Gran Colombia and MERCOSUR. Of course it has to be added that in the 1990s, their position was at the lower right of the curve, and that the development is rather catching up with

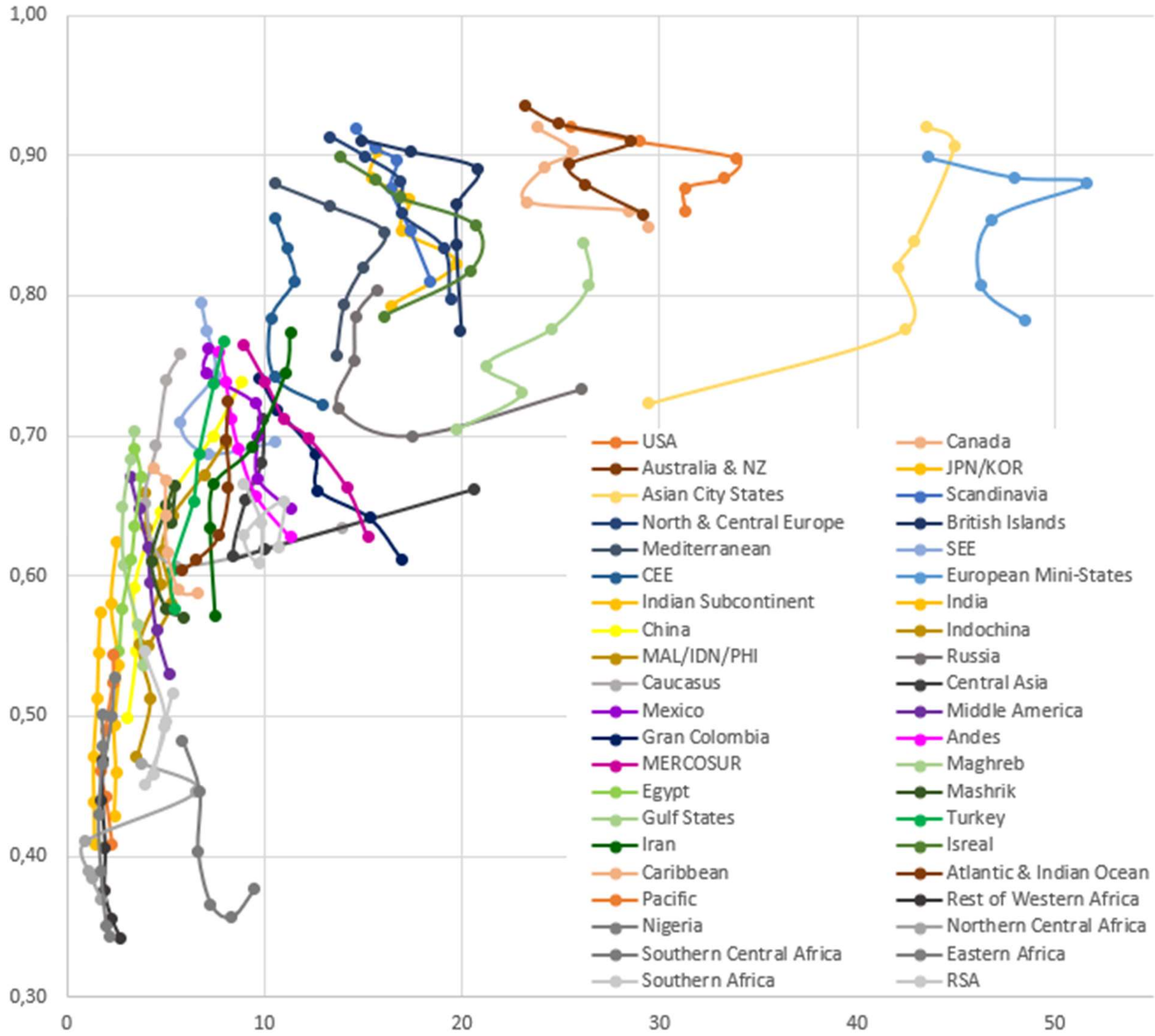


Figure 28: HDI explained by CF; timeline analysis of sub-regions, 1990-2015, 5-year intervals

human development and resource efficiency; however, the development from the lower right to the upper left of the curve could be used as an example for countries stagnating at the lower right, like the RSA, other Southern African countries like Botswana, and Central Asia.

3.3.3. Timelines of Land Footprints vs HDI

In contrast to MF and CF, the timelines of the land footprints explained by HDI (Figure 29) do all have a tendency to the upper left in the meanwhile, and only few regions started at very high footprints, namely Southern Central Africa, Russia and Central Asia, Gulf States and Anglo-Saxon New World as examples of countries with large areas and low population densities, and European and Asian City States as examples of densely populated countries, as it has already been indicated in the regression analysis. The development to lesser land use per cap, however, does rather derive from higher land use intensity than land protection, and can thus hardly been presented as a positive example. This shows with even more clarity that land use is not a suitable variable in the model

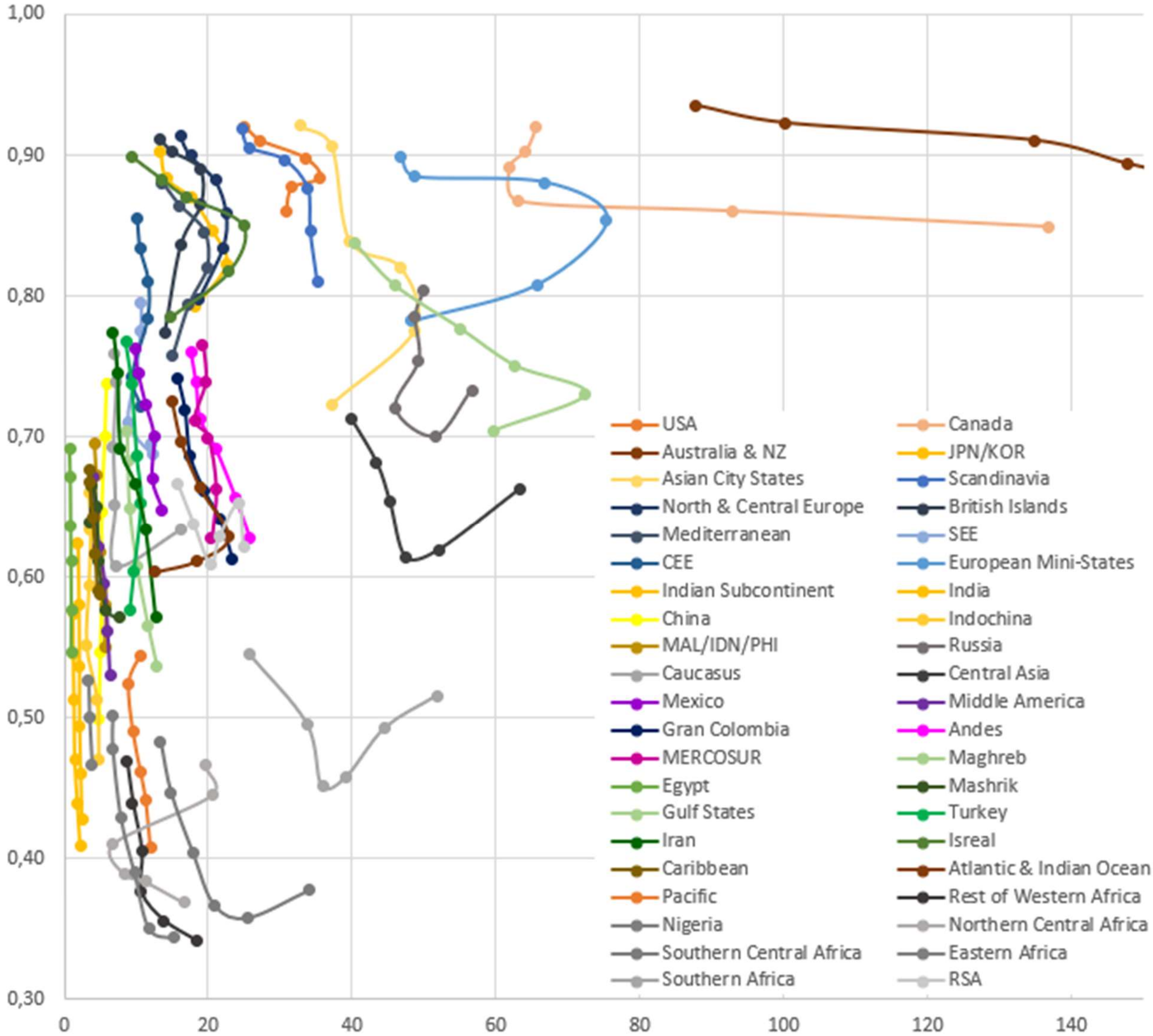


Figure 29: HDI explained by LF; timeline analysis of sub-regions, 1990-2015, 5-year intervals

presented in this thesis, apart from – possibly – intensive crops. This does not mean that the model ignores the pressures from land use, as by-products of intensive land use are, *inter alia*, high GHG emissions from forest fires, ruminants and fertilizers.

3.4. Cluster Analysis

In the previous thesis, the author has started to exploratively cluster the countries with regards to their position in the development diagram, HDI explained by MF, for 2012. In this chapter, the residuals from the following regression analyses will be used:

[1] $\ln(MF)_{i,t}$ = Intercept + beta $HDI_{i,t} + u_{i,t}$ (see Annex 2, Sheet 2)

[2] $HDI_{i,t}$ = Intercept + beta $\ln(MF_{i,t}) + u_{i,t}$ (see Annex 2, Sheet 3)

[3] $\ln(CF)_{i,t}$ = Intercept + beta $HDI_{i,t} + u_{i,t}$ (see Annex 2, Sheet 4)

[4] $HDI_{i,t}$ = Intercept + beta $\ln(CF_{i,t}) + u_{i,t}$ (see Annex 2, Sheet 5)

That means, the regression is carried out for MF and CF, each in both directions (with switched dependent and independent variable), to calculate the residuals of both variables for all countries for all years under review. Table 3 shows the 2015 residuals for a selection of countries, also indicating the trend since 1990. The first column shows the residuals of equation 1, the second column of equation 2, the third column of equation 3 and the fourth column of equation 4. If the residuals of 1 and 3 are positive, the MF/CF is higher than predicted by the model, if they are negative, the footprints are lower (less resource use per capita). If the residuals of 2 and 4 are positive, the HDI is higher than predicted, if they are negative, they are lower. The residuals of 1 and 3 are usually diametrical to those of 2 and 4 – data are to the upper left or the lower right of the curve; exceptions exist at the tails of the curve (compare the USA or Australia).

The data show (for details see Annex 2, Sheet 1) that most of the countries diverge to higher development, indicating that the overall regression curve has shifted upwards over time. The tendency that footprint residuals are declining over time does not automatically imply that resource intensity has declined as well, as the residuals are measured from the overall regression line, in which the upward shift over time is not considered. Nevertheless, the residuals can be very well used for an analysis of the position, which a country has in the model, and therefore for setting up clusters of countries.

The countries marked with a red background have a higher footprint than predicted, but a lower HDI.[10] These can be found to the lower right of the regression curve, and are usually resource-based countries, countries with a resource-intensive industrialization path, and unsustainable development. For countries with a green or blue background, the footprints are lower and the HDI is higher than predicted, therefore they can be found at the upper left of the regression line.[11] These countries have very different characteristics, but apparently a more sustainable development path, which should be an encouraging signal for further research. Interestingly, many countries in this group are islands and/or (former) socialist states. The countries marked in yellow have particularly high HDIs, but very different footprints; Luxembourg (as well as other very small states) can be found

Table 3 **Country**	**ZRE lnMF exby HDI**	**ZRE HDI exby lnMF**	**ZRE lnCF exby HDI**	**ZRE HDI exby lnCF**	**HDI**	**Cluster**
Germany	-0.63 (--)	1.43 (+)	-0.84 (--)	1.70 (+)	0.93 (+)	A1
Japan	-0.39 (-)	1.13 (+)	-0.47 (--)	1.30 (+)	0.90 (+)	A1
Czech Rep.	-0.06 (-)	0.80 (+)	-0.77 (-)	1.46 (+)	0.88 (++)	B1 to A1
USA	-0.04 (-)	0.90 (+)	0.15 (-)	0.90 (+)	0.92 (0)	A3 to A2
Australia	0.68 (~)	0.36 (~)	-0.06 (-)	1.14 (+)	0.94 (+)	A3 to A2
Barbados	-1.06 (--)	1.38 (++)	-0.30 (-)	0.80 (+)	0.80 (+)	C1 to B1
Cuba	-1.17 (--)	1.40 (++)	-1.18 (--)	1.40 (++)	0.78 (++)	C1 to B1
Gabon	-1.13 (-)	1.11 (+)	-0.98 (--)	0.94 (++)	0.70 (++)	C1 to B1
Côte d’Ivoire	-2.20 (--)	1.27 (++)	-1.33 (--)	0.10 (++)	0.47 (++)	D to C1
Luxembourg	1.48 (0)	-0.43 (~)	1.23 (-)	-0.01 (+)	0.90 (+)	A3
Kuwait	1.70 (-)	-0.94 (+)	1.69 (-)	-0.73 (+)	0.80 (+)	B2 to A3
Kazakhstan	0.66 (~)	-0.10 (+)	0.39 (-)	0.23 (+)	0.79 (+)	C1 to B2
China	0.28 (-)	-0.77 (0)	-0.22 (0)	0.52 (+)	0.74 (+)	C2 to B2
Botswana	2.22 (-)	-1.69 (+)	1.56 (~)	-1.00 (+)	0.70 (+)	C2 to B2
Guinea	0.48 (-)	-1.16 (+)	0.17 (-)	-1.02 (+)	0.41 (+)	D to C2
Niger	1.34 (-)	-2.08 (-)	0.28 (-)	-1.33 (+)	0.35 (+)	D to C2

Table 3: ZRE = standardized residuals, from overall regression analysis (see Chapter 3.2.1.); all numerical data in this table from 2015; signs in brackets: trend of this variable since 1990: ++ strong increase; + increase, 0 stable/stagnating, - decrease, ~ unstable); see in detail Annex 2, Sheet 1

[10] Further examples for this group are: Congo DR, Rwanda, CAR, Burundi, Zambia, Angola, Lesotho, Swaziland, Mali, Bolivia, Paraguay, Uruguay, Papua New Guinea, Kuwait, UAE, Saudi-Arabia, Oman

[11] Further examples for this group are: Madagascar, Laos, Myanmar, Haiti, Zimbabwe, Ghana, Sri Lanka, Tajikistan, Georgia, Azerbaijan, Croatia, Dominican Republic, Philippines

below the curve, the United States and Australia have recently crossed the curve from below to above, Germany, Japan and many other European countries can be found above the regression line.

Based on this analysis, the development state can be used as the second criterion for a cluster model; as the limits between low, medium and high development are rather arbitrary and shift over time, the author refrains from using specific numbers and explains the clusters in an abstract model. The basic system can be explained as follows: Cluster A contains developed countries, Cluster B consists of countries in transition, while Cluster C consists of developing countries; least developed countries (LDCs) can be found in Cluster D. Clusters B and C are subdivided into B1, B2, C1, C2, with the [1] to the upper left, and the [2] to the lower right of the curve. The tails are different: A is subdivided into A1 (above the line, higher efficiency), A2 (above the line, but lower efficiency), A3 (below the line). Cluster D cannot be subdivided, as the environmental footprint of LDCs is extremely low, and its variations cannot be described by this model. The cluster model is visualized in Figure 30:

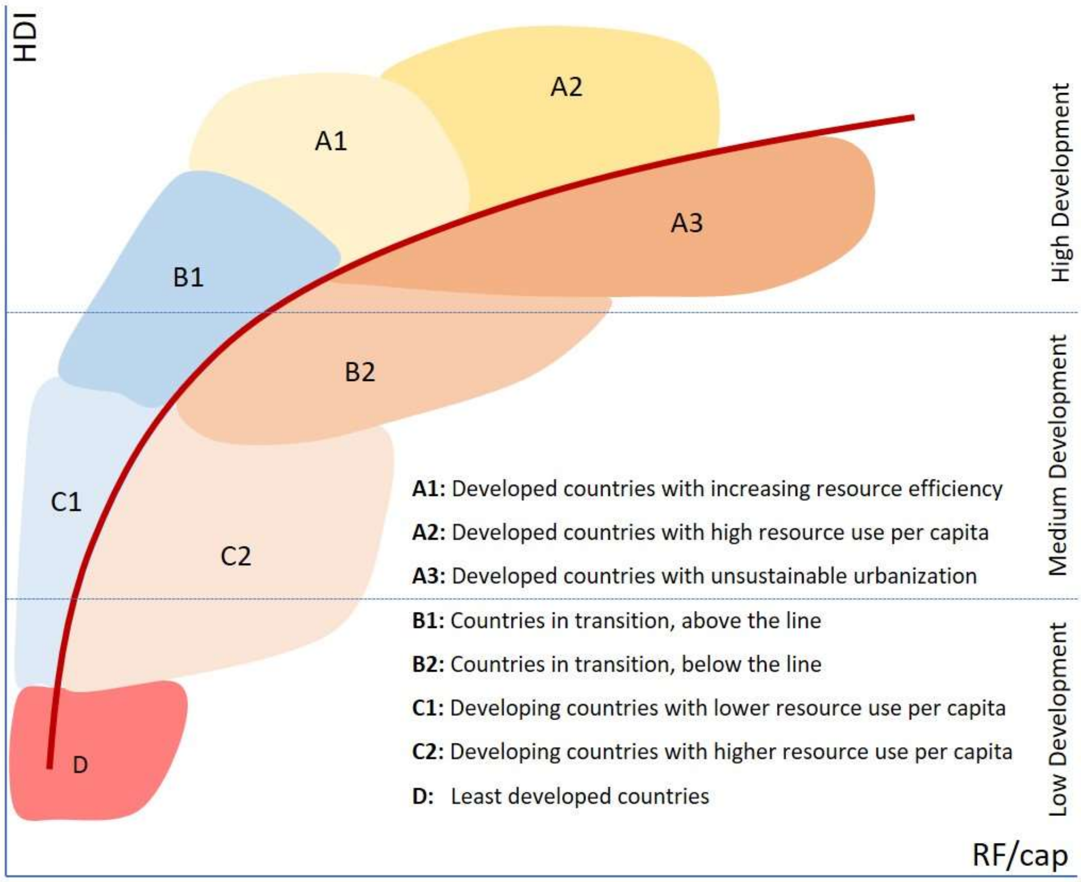


Figure 30: Sketch of Development Clusters with systematic numbers

4. Discussion

4.1. Applying the findings to model ESD

4.1.1. The Development Clusters and the Path of Development

As already indicated in the previous section, the position of a country in a certain cluster is not arbitrary. Whether a country is above or below the overall path of development, depends on various factors which will be examined in this chapter. Methodologically, as the environmental footprints are based on consumption instead of production (and thus considering trade effects), the economic sector composition of a country should not play an important role; however, all analyses have shown that resource-based developing states can typically be found in the lower right. Why this is the case will be subject to future research, for the purpose of this thesis it will remain as a fact that resource-based development is statistically more resource intensive, also in terms of footprints. Conversely, also the question why countries are above the path of development is yet to be solved; the finding that countries with less resource dependence (and thus secondary

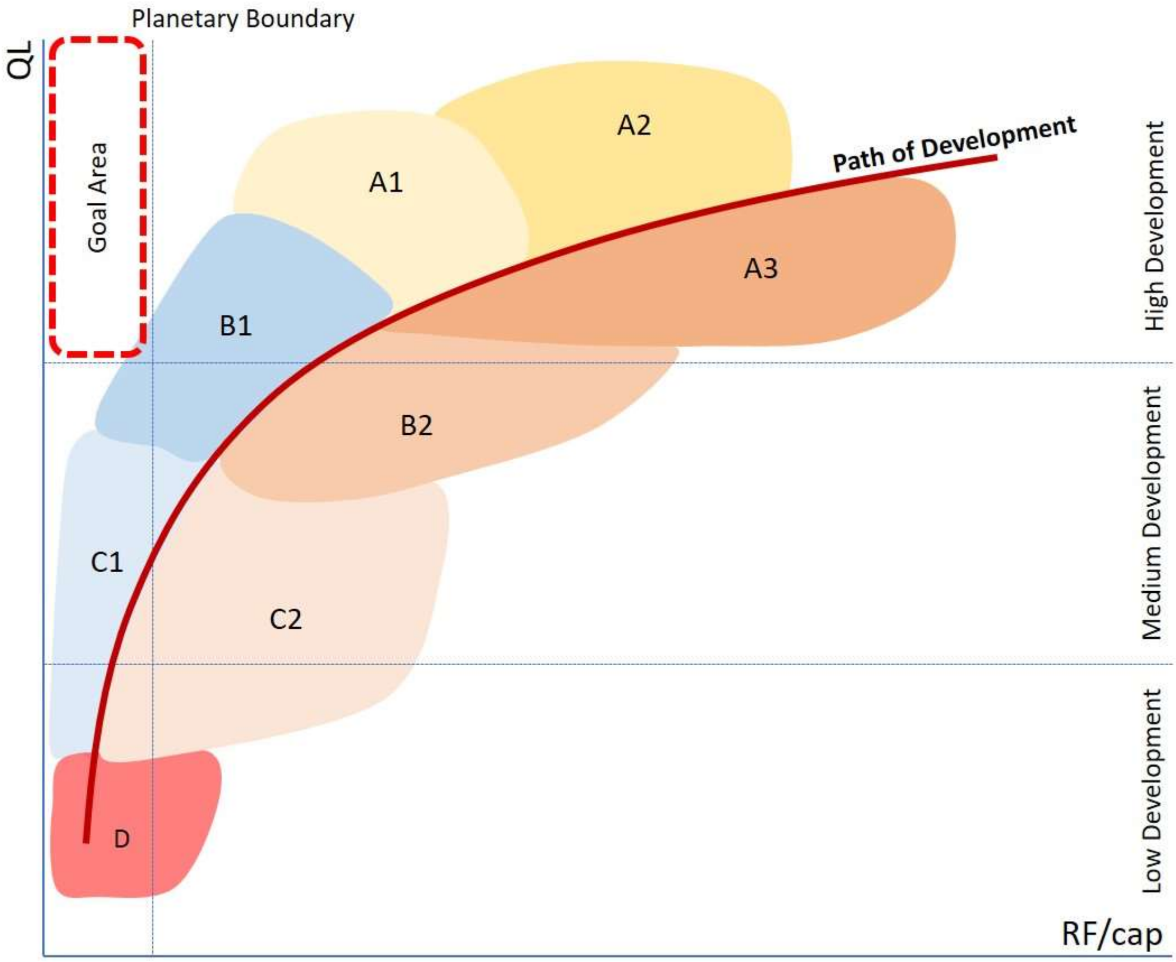


Figure 31: Sketch of Development Clusters, including PB, development levels and goal area

and tertiary sector account for a higher share), islands and countries with socialist history are statistically more likely to be above the path of development (among the developing and transition countries) may be a point of departure for future research.

In addition to these factors, which have already been discussed at the respective point of the analysis, the author wants to include two important concepts from ecological economics, planetary boundaries, and based on them, a goal for an environmentally sustainable development (ESD). As shown in Figure 31, the planetary boundary appears in this model as a vertical line, as it represents a maximum of natural resource use; how it can be measured, and how per capita figures can be added to the model at hand,[12] will be dealt with in the following chapters. In any case, the goal area is located below the planetary boundary per capita, and above the (arbitrary) line, above which human development, well-being or quality of life are considered to be high.

In accordance with the results presented above, natural resources suitable to be included in this model are all raw materials, to a certain extent crops, all greenhouse gases and grey water. As the latter two are emissions, it could be supposed that the model does also work for some other pollutants; however, this is not the case for pollutants whose emissions follow the EKC (see above, chapter 2.2.1.), like SO_2 or VOCs. As fossil fuels and CO_2 show particularly good results, it can also be assumed that energy use (and energy carriers, if they are not already included in either ores, e.g. Uranium, or biomass, e.g. ethanole) could also be integrated in the model. To what extent biodiversity loss could be included in the model remains a subject for further research; since biodiversity loss is also a long-term effect which is hardly internalized, the author regards it as very likely suitable for the model. For the purpose of the model presented below, all suitable environmental pressures will be, henceforth, abbreviated as "RF/cap" (environmental pressures, measured as resoure footprints, RF, per capita).

For the y-axis, the analysis has shown that both HDI and Happiness Index would theoretically be applicable, however, the latter with a slightly different slope and lower explanatory value; how these factors develop with increasing data quality, and to what extent which index does indeed describe quality of life, well-being, human development, remains for further research. For the purpose of the model presented in this thesis, it is beneficial to assume that indicators for quality of life generally contain GDP/cap or its

[12] Assuming a fair share approach regarding long-term development targets.

logarithm (reflecting the diminishing marginal utility of additional GDP/cap), or at least one constituent strongly correlating with it (e.g. disposable income).[13] This might be debatable, but seems reasonable since most multifactor models (such as the HDI) contain GDP/cap, GNI/cap or disposable income, next to other factors such as education, health, freedom to make choices, perspectives in life, democratic rights, safety etc. For this model, "QL" (quality of life) is defined as such an index and will, from now on, be used on all charts. Whether this model is suitable also for entirely survey-based indicators must also be addressed in further research.

Before the implications of the planetary boundary concept on decoupling and the path of environmentally sustainable development can be examined, it should be clarified how the path of development can be defined in an abstract way, and how changes in variables influence the path of development. The path of development is the overall regression line of quality of life as a function of environmental pressures (expressed as resource footprints) per capita per year.

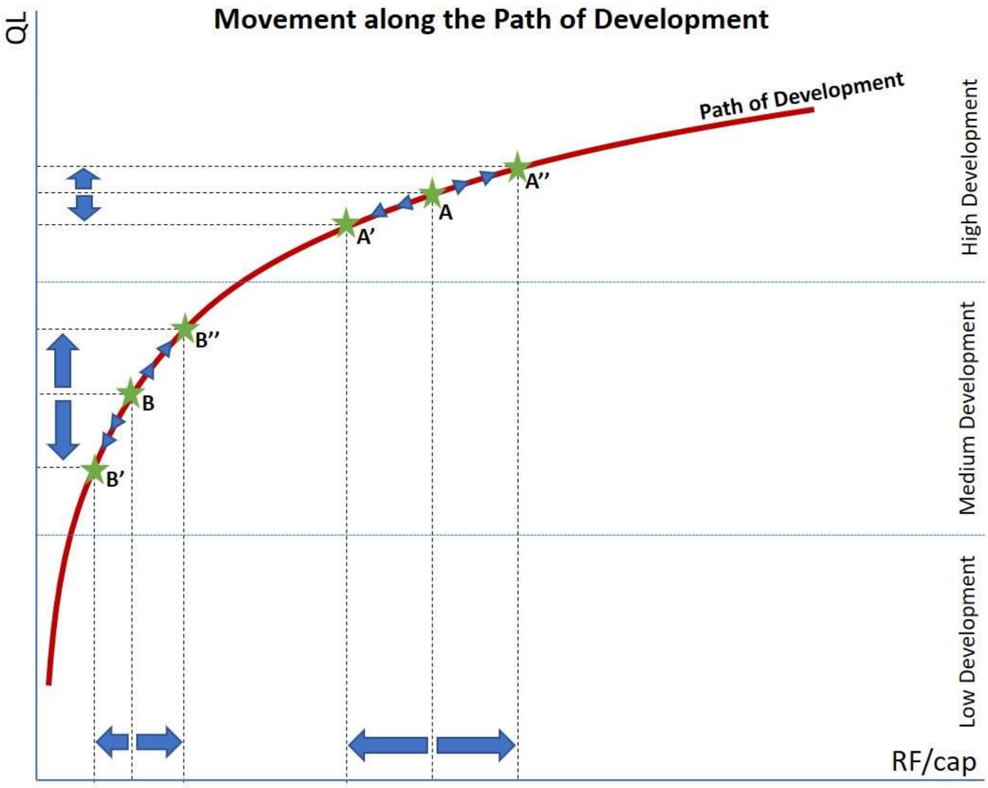


Figure 32a: Sketch of the Development Path, with movements along the curve

Figure 32a shows, how the movement along the path of development influences quality of life. From point A, a decline to A' or an increase to A" has a rather small effect, while

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[13] This assumption allows the assessment of feedback or rebound effects, i.e. the direct impact of GDP/cap or similar indicators on the position of the curve (upshifts or downshifts, see below).

a movement from point B to B' or B" leads to a huge change of the development state. A movement along the path of development occurs if, *ceteris paribus*, resource use per capita increases. Environmental pressures can be described by the total economic output Y (positive impact) and factors like resource sufficiency and emission mitigation measures (negative impact). Resource sufficiency could be disaggregated into further factors, for example obsolescence, consumer preferences and others. This implies that higher resource sufficiency, lower consumption due to a change in preferences, lower obsolescence or better emission mitigation measures (tougher regulation) would, *prima facie*, lead to a lower GDP (which is linearly connected with RF/cap) and a lower QL, with the effect on QL depending on the stage of development, due to the changing slope of the overall regression line. The same is true for an increase in circularity, as far as it leads to the substitution of certain economic sectors. This makes sense, insofar as lower obsolescence is negative for secondary industries, higher circularity leads to declining mining activities and emission mitigation measures are very costly.

The strength of this effect, the GDP elasticity of environmental impact mitigation, depends on the resource and emission dependence of a country (in footprint terms, thus linked to the consumption patterns). Highly developed countries with a higher tertiary share will probably have a lower elasticity of environmental impact mitigation. For some

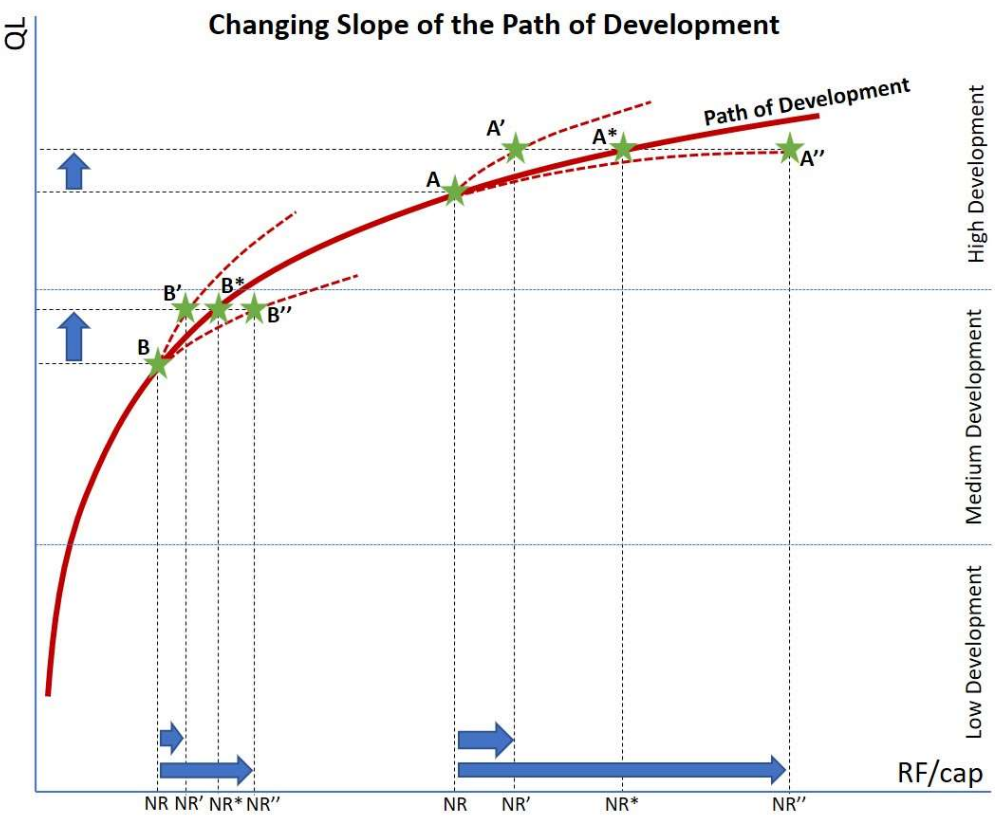

Figure 32b: Sketch of the Development Path, with changes in slope

of the factors named before, there is a counter development (damping feedback mechanism) due to directly increased GDP, coming from newly emerging sectors compatible with circular economies, e.g. recycling instead of mining, high-tech and services instead of mass production (compare Section 2.2.3.). Since GDP/cap is (at least in the form of disposable income) one of the variables included in QL (see above, definitions earlier this chapter), this feedback would be implemented into the model via an upshift to another path of development. Whether it is stronger or weaker than the initial downward movement along the curve depends on the respective stage of development, the slope of the curve and external effects.

Figure 32b shows the change in slope of the path of development, leading to a movement from A to A' or A" instead of A*, and B to B' or B" instead of B*, respectively. The slope can be described as the marginal effect of another unit of resource use on QL; thus, the strength of the effect depends on the elasticity at the point of change. Accordingly, factors influencing the slope are connected to resource efficiency (in contrast to resource *sufficiency*, which is an important factor for the movement along the curve, see above); resource efficiency does not automatically go hand in hand with conventional economic efficiency, which is linked to input-output factors and price. Considering the results of the cluster analysis, the composition of economic sectors seems to influence the slope of the curve, even though RFs are consumption-based indicators. The concept of a circular economy is also linked to the slope, as far as it concerns the more resource efficient production of additional goods (and not the substitution of economic sectors).

Figure 32c shows the shift of the path of development; a shift has a constant effect at all development stages and is triggered by the change of a variable on the y-axis, like for example equality, societal recognition, personal freedom, democratic participation, health status, life satisfaction, safety, security and many other possible factors influencing quality of life. As mentioned above, also the increase in GDP/cap leads to an upshift of the development path via an increased disposable income. An upshift as a result of decoupled economic growth has already been observed (Steinberger and Roberts 2010). It is important to mention that changes in economic policies would not lead to an immediate jump to the respective point in the chart, but rather to a convergence towards the new path of development.

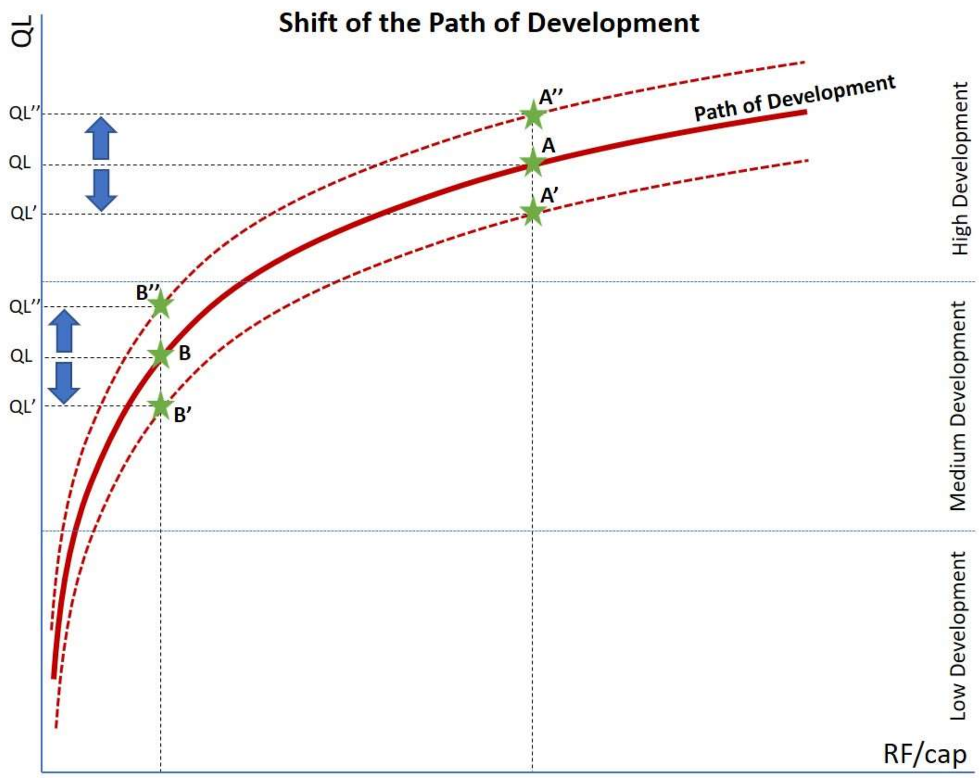

Figure 32c: Sketch of the Development Path, with possible shifts

In addition to the socioeconomic factors discussed above, the population size and density are of importance when dealing with per capita figures. Changes in population influence this model in multiple ways: First, assuming a constant area (neglecting artificial land area increases through accretion or land losses through flooding and desertification), both increasing population size and population density lead, *ceteris paribus*, to a movement to the left. Additionally, also the PB/cap changes (see below), and population density might have direct effects on well-being (social factors, leading to a shift) and resource efficiency (e.g. urbanization, effect on slope). Thus, the overall effect of population size and population density changes cannot be explained from this analysis.

To sum up, there are three possible mechanisms how a countries position at its development path can be influenced: (1) movement along the curve; (2) shift of the curve; (3) change of the slope of the curve. The question which underlying economic, social and cultural factors determine which of these movements cannot be conclusively assessed with the data used in this thesis and is left for further research. These findings could be very well used to analyse the timelines of individual countries; on the other hand, timeline analyses could be used to falsify the model presented in this thesis.

4.1.2. Decoupling and the Path of Environmentally Sustainable Development

After explaining the development clusters and defining the development path, an attempt to fit the model into the concept of decoupling and the planetary boundaries seems possible. Although the planetary boundaries have not been calculated in this thesis, it can be reasonably assumed that the threshold introduced as a vertical line is located relatively close to the y-axis, compared to the current resource footprints. This can be derived from previous studies (Tukker 2016) and from the fact that many planetary boundaries have already been transgressed (Steffen, et al. 2015, Rockstroem 2009). This is even more the case when it comes to per capita figures of developed countries.

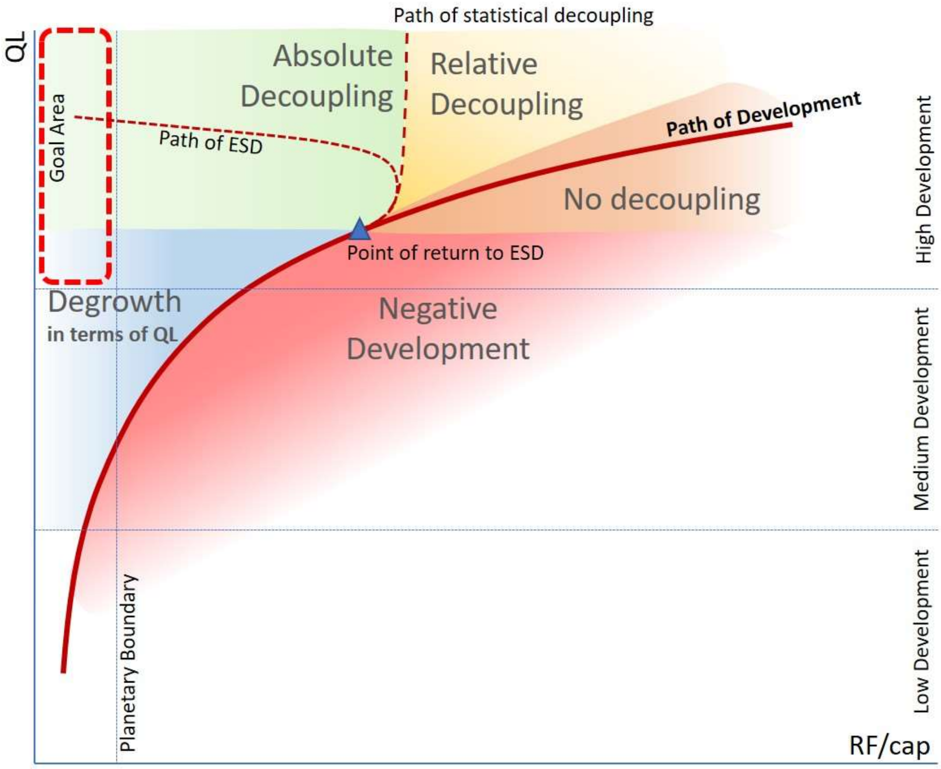

Figure 33a: Sketch of the Development Path in the context of decoupling

Figure 33a shows a planetary boundary (as an abstract composite of all environmental pressure categories) and introduces a theoretical path of statistical decoupling (referring to a correlation close to 0) between environmental pressures and quality of life. This is a development path occurring after a point of return to sustainable development which is not at all correlated with the independent variable (RF/cap), and does therefore (assuming positive development) change to a vertical line. From the point of return to sustainable development, any development along the original path can be classified as "no decoupling" (orange area); any development path between the original development path and the path of statistical decoupling can be classified as "relative decoupling"; any positive development path to the left of the path of statistical decoupling (*including that path itself*) is "absolute decoupling". Below the point of return, the development is negative, i.e. attached with a decrease in QL. It is important to mention that "degrowth" in this chart is different from degrowth in the discussion between neoclassical and ecological economists, as the chart at hand does not refer to GDP, but to QL.[14]

What is much more important is the fact that, if the planetary boundary is already transgressed, even absolute decoupling does *not automatically* lead to entirely reaching the goal area.[15] In order to reach this area, the "path of environmentally sustainable development (ESD)" must be introduced, which has totally different characteristics than the path of statistical decoupling; it could be phrased as a continuous and sufficiently vigorous absolute decoupling, without phases of re-coupling or stagnation. Figure 33b shows the points of return to sustainable development at six different stages of development, together with the necessary sustainability paths, compared to the statistical decoupling paths. The green asterisks show the points, at which statistical decoupling and the path to ESD depart from each other. The further the planetary boundary has already

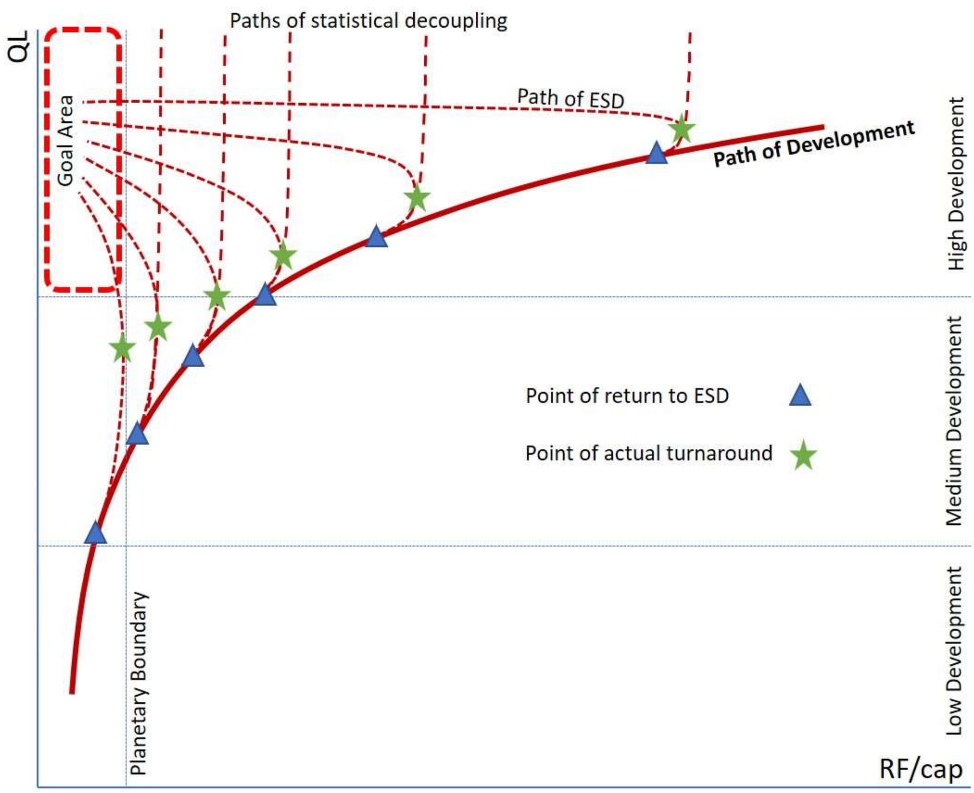

Figure 33b: Sketch of the Development Path with possible Paths of ESD

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[14] It would only be relevant in this discussion, if GDP/cap is regarded as the only measure for QL. For the relationship between the ESD model, the GDP and degrowth see Chapters 2.2.4, 4.1.3.

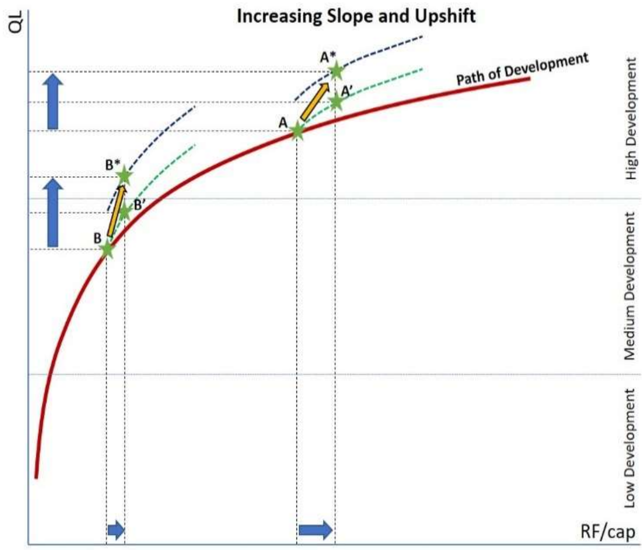
[15] *Stoknes* and *Rockstroem* also differentiate between green growth, requiring absolute decoupling, and "genuine green growth", requiring "sufficient decoupling" (Stoknes and Rockstroem 2018).

been transgressed, the sharper is this actual turnaround, and the flatter the remaining path of ESD is required to be.

These findings are indeed concerning, particularly as several PBs have already been transgressed on a global scale (see above, Section 2.2.2.). Although the shape of the path of ESD has already been observed in the data (compare the timeline analysis of material footprints for many European countries, Japan, Korea, the United States and, additionally, of carbon footprints of Latin American countries and other countries in transition), the further development towards the goal area is questionable. That is, as the turning point in many of the mentioned countries took place during the economic crisis after 2008, and not as a result of structural changes; since, the regional timelines are rather stagnating (compare Section 3.3.). The author wants to recall that, although a decoupling was already observed for the late 20th century, a re-coupling took place around the turn of the millennium, and that existing studies have found decelerations and yet again accelerations of environmental pressures in relation to quality of life indicators (Cibulka 2017, Pothen and Welsch 2019). Therefore, it will be even more important to develop policies towards the path of ESD, and not to remain stagnating far beyond the planetary boundaries.

How difficult it might be to practically turn to a path of ESD is shown in Figures 34a and 34b. Utilizing the elements previously developed, these figures compare two possible combinations of movements involving the path of development. The condition for a successful turn to environmentally sustainable development looks as follows:

Actual Path of Development = Path of Environmentally Sustainable Development



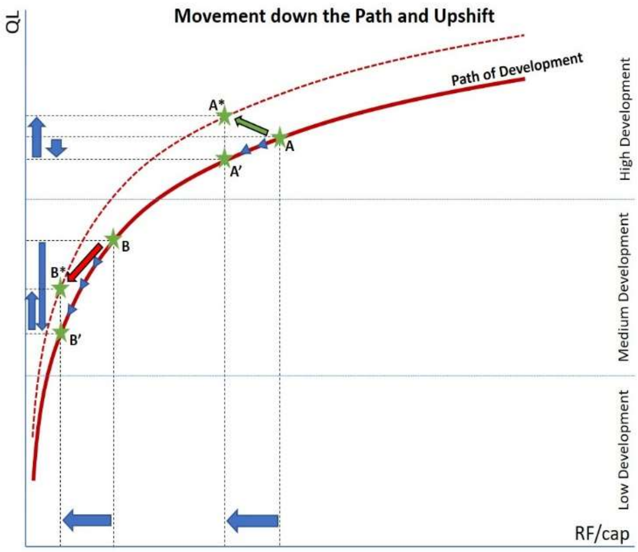


Figure 34a: Combination of slope and upshift | Figure 34b: Combination of downward movement and upshift

The first attempt to find a suitable combination shows the combined application of a higher slope and an upshift (Figure 34a), but without any movement along the original path of development. This attempt results in, *ceteris paribus*, an increased QL at still rising RF/cap, with the new, amended development path being close to the path to full statistical decoupling (yellow arrows, in the best case converging towards a vertical development path). This result fulfils the condition only, if the planetary boundary is not transgressed. Therefore, it seems clear that, in order to fulfil the condition for countries already beyond the planetary boundary, a movement down the path of development must be considered an option.

As stated above, a downward movement could be triggered, *inter alia*, by a shrinking economy, by stricter pollution control and stricter regulations, but also by decreased obsolescence and more circularity, higher resource efficiency and product services. Factors like the latter also lead to positive feedback or rebound mechanisms which might even exceed the economic losses from shrinking sectors, depending on the stage of development. These feedback mechanisms are assumed to exist in Figure 34b; the green arrow from A to A", with A' being the theoretical endpoint without positive feedback, looks like a successful attempt to meet the condition set out above. Therefore, it seems worthwhile to link these findings to research on feedback or rebound effects of "green sectors", like circular economy, resource efficiency and product services (compare Section 2.2.2.).

A shrinking economy (e.g. due to a crisis or due to policy-induced limited economic opportunities), stricter pollution control or regulations without direct feedback or rebound effects would require more complementary measures, in particular for increasing QL via exogenous factors. This must not be understood as an argument against regulation in general; it is, still, important to mention that taking unsuitable measures at the wrong stage of development might result in net losses of QL, illustrated by the red arrow between point B and B". This is another reason, why tailormade solutions for each development cluster (with regards to special circumstances like water scarcity) would be an important tool, which could be set up based on the ESD model (see chapter 4.2.3.).

In the following chapter, based on the examination of the path of development and its relationship to the path of ESD, a model giving a theoretical overview over the relationship to the GDP/cap (and thus to the question of growth versus degrowth) is derived.

4.1.3. Relationship to conventional growth models

Since even a full statistical decoupling would not be sufficiently sustainable after transgressing planetary boundaries, it is important to discuss how turning to a path of ESD would affect the GDP, and thus the conventional growth model.

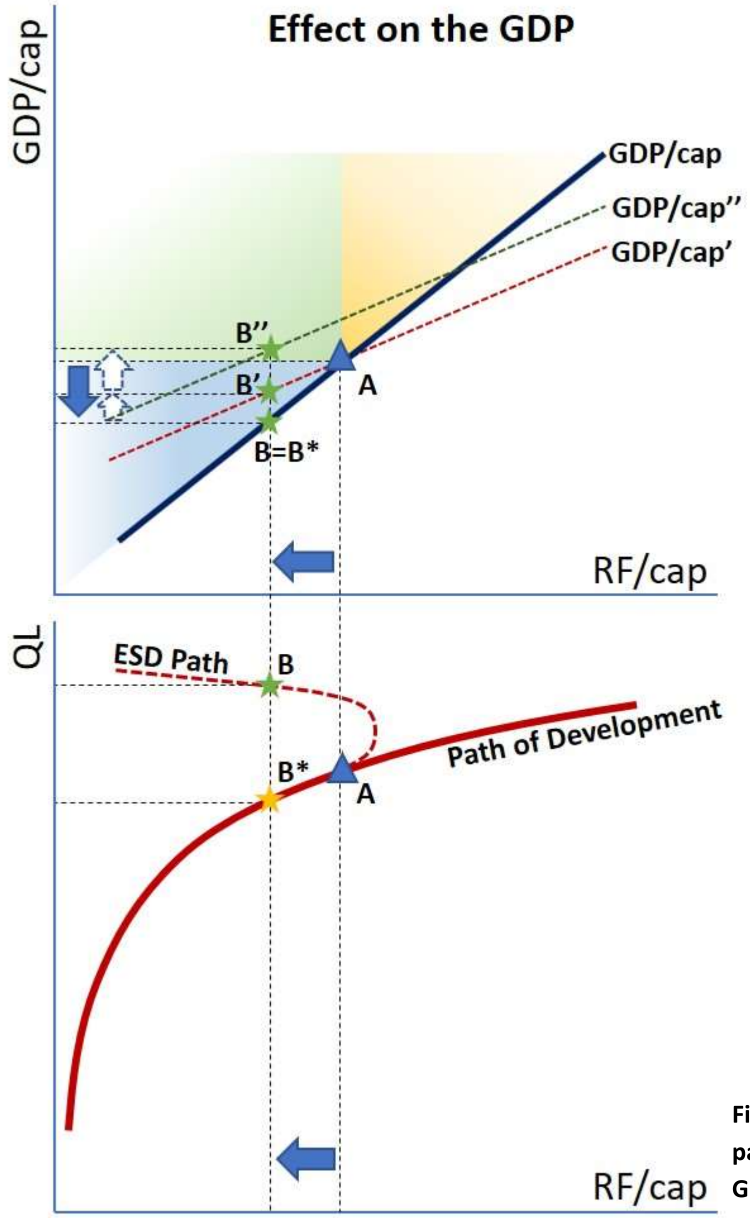


Figure 35: Effects of changes of the path of development on the GDP/cap

Figure 35 shows the known chart with the path of development and one arbitrary path of ESD (the chart below), starting with point A, a state of development after transgressing the planetary boundary. The path of ESD to point B implies already, as previously explained, a movement to the lower left and a subsequent upshift to a higher path of development. The upper chart shows GDP/cap as a function of RF/cap, in its linear shape as described in the analysis (see above, Section 3.2.1. (Steinberger and Krausmann

2011)).[16] The coloured areas are chosen in accordance with the decoupling sketch presented in Section 2.2.3.

Marking off points A and B at the GDP/cap illustrates a decline in GDP, although QL is still rising, if the path of ESD is successfully followed. The feedback or rebound effects introduced above could influence the GDP/cap in two ways: (1) decreasing the slope of the linear curve close to zero (the slope can be regarded as the environmental pressure elasticity of the GDP/cap) by making the economy less dependent on resources, and so reaching a point like B'; (2) shifting the GDP curve upward, by any other economic variable increasing the GDP, and so reaching a point like B''. Both B' and B'' can, depending on the strength of the feedback or rebound effect, be above or below point A. As a result, although QL has increased, GDP/cap might have risen or fallen. This result does strongly support the argument of economists advocating a-growth and post-growth approaches: It does not matter whether GDP/cap grows, since prosperity without growth is possible.

Critics could argue that this part of the model is merely based on the logarithmic relationship between GDP/cap and HDI, and this relationship would mostly exist because the HDI contains the logarithm of GDP/cap as one out of three variables. This is true, but only to a certain extent:

(1) That the HDI is set up in this way is not arbitrarily chosen but based on the cognition that marginal utility of consumption decreases the higher it gets. Under the assumption that QL is maximized, and not GDP/cap as an end in itself, the logarithm of disposable income is the more appropriate component of a multifactor model.
(2) Education and life expectancy, as the other two factors used for the HDI, do also most probably level off with higher environmental pressure and are supposedly less correlated with resource use and GHG emissions in the first place.
(3) Although it contains many more factors than the HDI, a logarithmic regression explaining the Happiness Index by RFs does also reach very high explanatory values (see above).
(4) Existing studies indicate that there is also a logarithmic relationship between GDP/cap and average life satisfaction, a subjective measure of well-being (Knight and Rosa 2011).

[16] The two charts are in fact a disaggregated and abstracted version of the scatter charts in Section 3.2.1.

This further supports the hypothesis that, independently from methodological issues with the HDI, the relationship between GDP/cap and happiness or life satisfaction levels off at a certain point. Therefore, although the model is to a large extent based on the HDI, the overall shape of the path of development and its relation towards the GDP/cap are reinforced by the analysis of indicators measuring happiness and life satisfaction.

The model presented in Figure 35, based on the results presented above, could be made compatible with classical economic growth models, as the y-axis with GDP/cap could be horizontally transposed to another chart. In that chart, classical growth predictors could be applied, like for example the Green Growth Model by *Hallegatte et al* (Hallegatte, et al. 2012). Future studies could, based on this connection, evaluate propositions and predictions derived from the model at hand, together with *Hallegatte's* propositions about changes along the imperfect Production Frontier (Hallegatte, et al. 2012)).

4.1.4. Internalizing Planetary Boundaries per capita

Finally, the issue of planetary boundaries per capita must be tackled. This is important, because on the one hand, measuring planetary boundaries per capita is a problem as such, and on the other hand, as an exogenous PB/cap would appear as a constant, which could lead to wrong conceptions regarding possible effects of population changes (since population size is endogenous to the x-axis, as divisor of the environmental pressures, its influence on the PB/cap must also be assessed). Figure 36 consists of the known chart, but with the difference that the PB/cap is now an endogenous variable. Its horizontal shifts are explained by the second chart, showing population size (in absolute numbers) versus RF/cap. The product of the two axis variables is the RF in absolute numbers. The 45°-line, as the distance from the origin, indicates resource use in absolute terms.

Due to the application of the MRIO approach, the absolute amounts of material footprints (MF) and GHG footprints (CF) are globally the same as aggregate material use (e.g. aggregate DMC) and GHG emissions (see Section 2.2.6.); hence, the planetary boundaries in absolute numbers can directly be used to feed in this model. The most important condition to be fulfilled is that the PB(abs) must be converted into annual flows, which seems possible for all livestock and pollutants (as they are part of the biochemical nitrogen, carbon, or sulphur cycles, and thus have a certain recovery function), but not so easily for inorganic materials or very long-term organics (like crude oil, plastics). For the latter, boundaries in the form of annual flows could probably be converted with reference to their estimated exhaustion or a measure for scarcity.

With the absolute PB being a constant axis product, it can be defined as a constant area in this chart (for point A, this is the rectangle between the origin and point A). The curve, under which the axis product at any point is constant, is per definition a hyperbola, which can for example be called PB Frontier. The population size in absolute numbers is a constant, horizontal line. The intersection between the hyperbola and the population constant is the average PB/cap in the same units as the RF/cap. To internalize the PB/cap into the ESD model, a line can be drawn from point A into the upper chart, where the corresponding intersection refers to the stage of development, at which the planetary boundary is transgressed. An increase in population leads to a new intersection, point A'. Therefore, PB/cap shifts to the left. Via a connection to any population growth model, through horizontally transposing the y-axis to another chart with time as the independent variable, also the population growth could be internalized, allowing for scenarios how the PB/cap would change over time, thereby establishing a moving target.

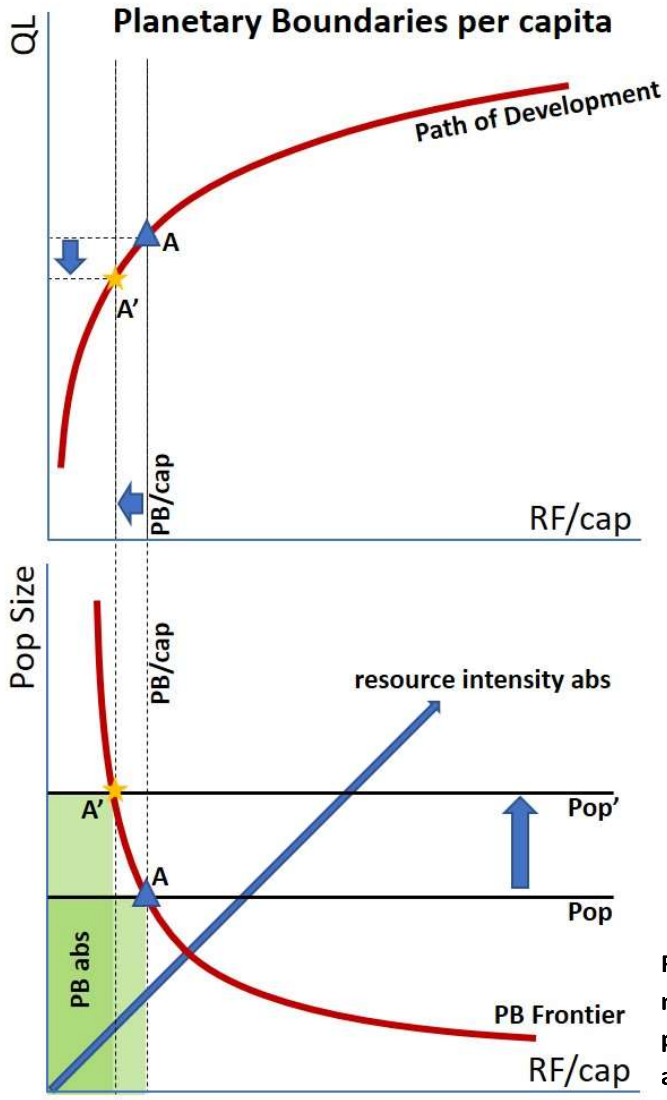


Figure 36: Shift of the PB/cap, via a mathematical model based on population size and RF/cap, with PB abs as a constant area.

In order to test its empirical foundation, the author has set up this part of the model as a scatter chart; indeed, first attempts already depict very well both the hyperbolic structure, as well as the increase in resource use of some countries (see Annex 1, Sheet 1, scroll down). By assuming land area to be constant (ignoring accretion, land degradation, inundation etc.), population density could be brought in via a proportion model.

4.1.5. Overview and Compatibility of the ESD Model

To summarize, the model describing the path to environmentally sustainable development starts from the empirically proven logarithmic shape of the path of development and contains development clusters differentiating between countries with different resource intensity. Based on the concepts of planetary boundaries and decoupling, a sustainable

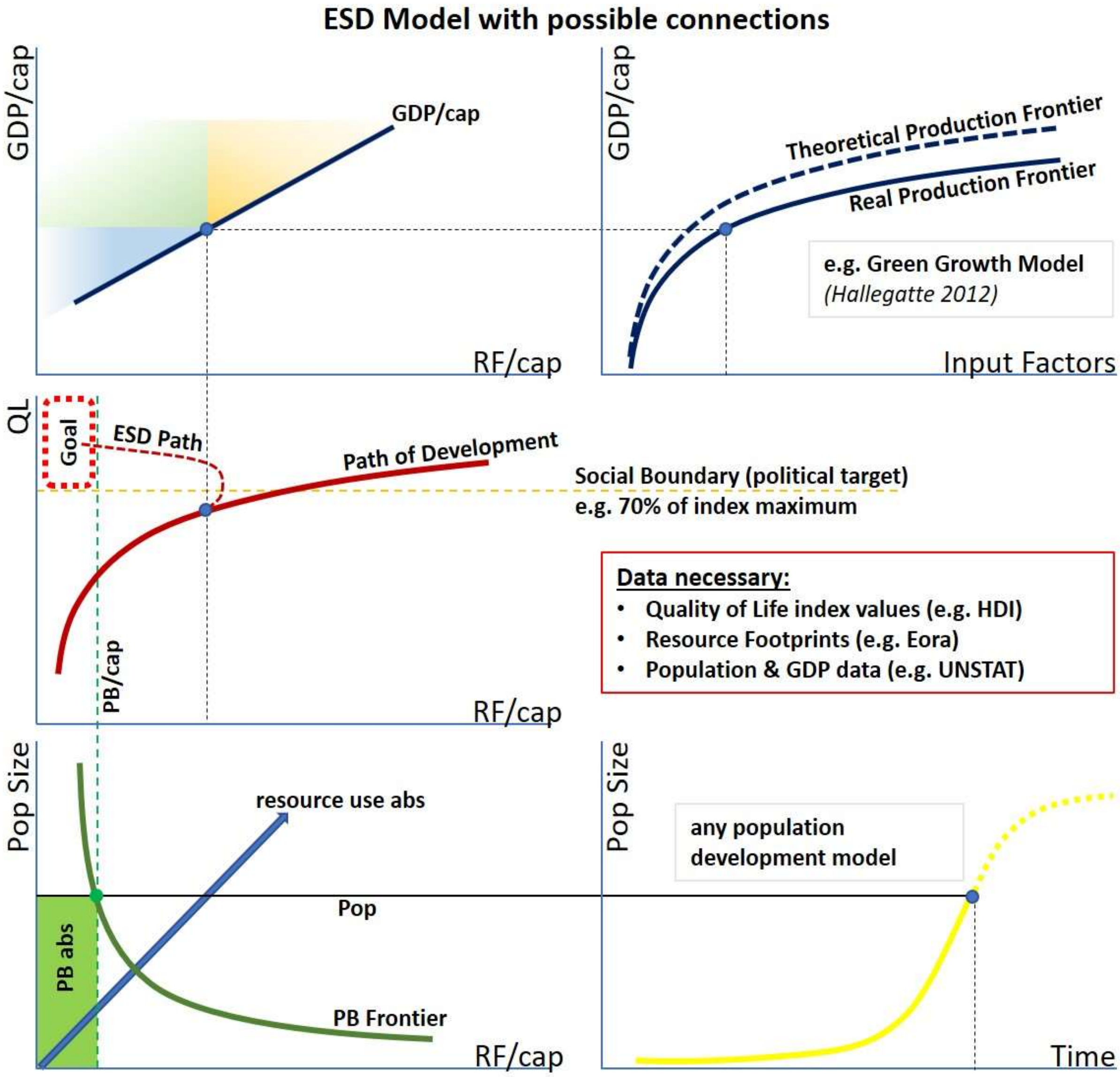


Figure 37: ESD Model with possible connections; middle left: ESD model; upper left: relationship GDP/cap and RF/cap, connected to Green Growth Model (upper right); bottom left: PB frontier to internalize PB/cap, connectable to any population model (bottom right).

development goal is envisaged; however, the path of ESD cannot be taken by means of decoupling, if planetary boundaries are already transgressed. In this case, a downward movement might be necessary, thereby relying on feedback or rebound mechanisms and complementary measures, damping its *prima facie* negative impact on the economy.

As the GDP/cap vs RF/cap curve is linear, its elasticity needs to be reduced by lowering dependence on resource use, if degrowth should be averted. Nevertheless, increasing quality of life is also possible when accepting non-growth or degrowth in terms of GDP/cap, above a certain (not yet specified) level of development. Finally, planetary boundaries per capita can be included in the model if estimates for annual flows are available, illustrated as the hyperbolic PB frontier, whose intersection with the population gives the variable PB/cap. This, plus the social boundary, stipulate the goal of ESD. The social boundary above which quality of life can be regarded as "high" depends on a political decision, e.g. an agreement from within the UN framework.

Figure 37 gives a complete overview of the model (the three charts on the left side), also indicating possible connections to economic growth and population models. The data to be fed into the model are (1) quality of life index values; (2) environmental footprints; (3) supplementary population and GDP data. Whereas the latter are relatively easy to compile, the first two are raising further questions. Regarding quality of life, economic multifactor models are necessary, which should aim at optimally explaining happiness or life satisfaction; instead, psychological or sociological surveys could be used, however, in order to enable economic interpretation, multifactor models are needed again. Regarding resource footprints, differences in environmental pressure development patterns can only be analysed via disaggregated footprints. For an overview over the stage of development of a country along the development path, also combined footprints could be applied, leading to further methodological issues such as finding a common physical unit.

The two charts to the right of Figure 37 are not an integral part of the model explained in this thesis, but existing models that are compatible with the model at hand. The Green Growth Model by *Hallegatte et al* is based on the Solow Model, but with adjusted input factors and the differentiation between the theoretical and the real production frontier, accounting for economic imperfections. Population growth models typically show population size development over time, with the current development state being at the end of a period of exponential growth (already levelling off). A further deceleration is usually expected, but with different scenarios. Connecting such a model to the model at hand would allow estimating the position of the PB/cap over time. However, a link to the charts "GDP/cap vs RF/cap" and "QL vs RF/cap" is not yet included, therefore not yet internalizing population size in the core model. For GDP/cap, this would probably be possible via the economic growth model; for RF/cap, another extension of the model would be required which goes beyond the scope of this thesis.

4.2. SDG Interactions and other Fields of Application

Shortly after the official launch of the SDGs, scholars proposed different approaches to deal with the network characteristics, assuming that in general SDGs would reinforce each other, but that setting priorities and avoiding counteracting measures would be necessary. The range of analyses reaches from network analysis on the basis of algorithms (Le Blanc 2015, Mohr 2016) over a seven-point typology of interaction (Nilsson, Griggs and Visbeck 2016, International Council for Science 2017), to a combination of both (Weitz, et al. 2018). The seven-point typology uses the categories indivisible (+3, inextricably linked to the achievement of another goal), reinforcing (+2, aids the achievement of another goal), enabling (+1, creates conditions that further another goal), consistent (0, no significant positive or negative interactions), constraining (-1, limits options to another goal), counteracting (-2, clashes with another goal), and cancelling (-3, makes it impossible to reach another goal).

A network analysis of *Mohr*, using degree, betweenness and eigenvector, suggests that SDG 12 (responsible consumption and production) is the most central of all SDGs, followed by SDG 1 (no poverty), SDG 8 (decent work and economic growth) and SDG 10 (reduced inequalities (Mohr 2016)). At the same time, *Weitz* shows that most of the negative interactions occur with SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), SDG 13 (climate action), SDG 15 (life on land) and SDG 17.11 (SDG 17 target "export from developing countries"), which are, with the exception of the latter, environmental SDGs (Weitz, et al. 2018). These results indicate that, while the economic SDGs seem to be in the centre of the system and highly reinforcing each other, ecological SDGs are conflicting with either each other or with socioeconomic goals. Accordingly, the question how to achieve sustainable development remains, also within the SDG framework, factually unsolved.

This issue could be a possible field of application for the ESD model. First of all, a country specific analysis which planetary boundaries have already been (or being about to be) transgressed would be possible, thereby showing priority areas for specific resource use categories. This would enable taking into consideration more specific issues such as water scarcity, deforestation and land degradation, and to set the respective indicator to the highest priority. This step requires the utilization of the ESD model in a disaggregated form (separate footprints), and a correspondence table matching environmental footprints with SDGs. Due to the specific nature of the planetary boundaries, the first step needs to take place on the level of indicators, mostly within SDG 6 (water), SDG 13 (climate) and SDG 15 (land use, biodiversity). Some PBs are most probably linked to more than one SDG indicator. In a second step, it is of major relevance in which of the development clusters along the path of development a country is generally located, and in which direction the country is developing. For each development cluster, priority profiles on target levels could be created. Cluster A1 (very highly developed countries with increasing resource efficiency), for example, should most probably prioritize environmental SDG targets, renewable energy targets and sustainable urbanization and consumption targets. For cluster D (least developed countries), in contrast, targets operationalizing SDG 1 (end poverty), SDG 2 (end hunger) and SDG 3 (health) would certainly be of major importance. Accordingly, all SDG targets would need to be broken down to all development clusters, so that a number of priority targets per development cluster can be defined, which goes far beyond the scope of this thesis.

Finally, results of network analyses could be used as a catchall element, valid for all countries. As a result, the priority hierarchy among the SDG targets should be as follows:

1. Environmental priorities
   - Indicator level, mostly of biosphere-related SDGs
   - Matching planetary boundaries with SDG indicators
   - Few indicators (depending on PB transgression), highest priority
2. Cluster priorities
   - Target level, mostly of society-related SDGs
   - Defining several priority targets for each development cluster
   - Several targets (depending on development level), high priority
3. Network priorities
   - Goal level, mostly economy-related SDGs
   - Network analysis, defining SDGs with the strongest positive network impact
   - Goals with strong linkages, general priority

This approach reflects the findings from Section 4.1. and links the path of ESD to a normative concept. As a result, less developed countries would rather focus on economic and societal development, and highly developed countries rather on environmental and sustainability issues, reflecting historical responsibilities. It is also in line with the wedding cake model (see Figure 38 (Stockholm University 2016)), according to which the society is embedded within the biosphere and the economy within the society.

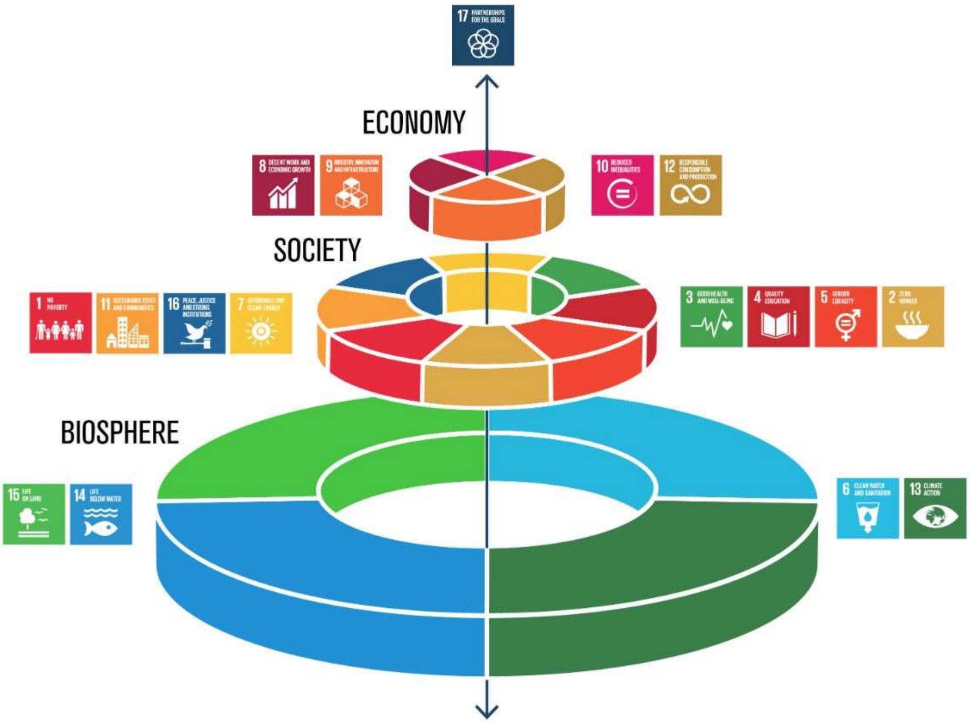


Figure 38: "Wedding Cake" model (Stockholm University 2016)

The priority hierarchy suggested above could be used for further related purposes as well. First of all, since the ESD model is based on resource footprints, supporting developing countries (net-exporters) to increase their resource efficiency would directly result in lower footprints in industrialized, net importing countries. Utilizing it for economic policies would, thus, encourage industrialized countries to boost their engagement in mechanisms like the CDM. The same is true for development aid in general, although, admittedly, geostrategic purposes have in praxis an even higher priority. Nevertheless, the model could still be used to achieve a globally more efficient distribution of development aid and CDM funds; interdisciplinary research with political scientists could even lead to a common priority matrix, including both environmentally sustainable development and geostrategic considerations. Finally, negotiations of international treaties dealing with ESD related issues could be supported by introducing a more differentiated approach than the traditional distinction between industrialized and developing countries.

5. Conclusion

5.1. Summary

Following the hypotheses (see Chapter 2.3.), regression analyses have shown that the relationship between resource footprints and quality of life can be described by a logarithmic curve, and that the relationship between RFs and GDP/cap is, in contrast, linear. These results are clearly opposing the Environmental Kuznets Curve, which seems to be applicable for pollutants with an immediate impact only, while the pressures analysed in this thesis are of long-term relevance. Moreover, the structural differences between GDP/cap and quality of life, in particular at the tails of the curve, are striking; this supports those who argue in favour of a-growth or post-growth, i.e. the recently developed paradigm that factors such as quality of life, development or prosperity should be maximized in a sustainable way, instead of focussing on growth of GDP/cap.

In a next step, utilizing the regression residuals, development clusters have been defined; the clustering criteria are the position of a country along the development path (whether it is below or above), and the stage of development. Departing from these clusters, the concepts of decoupling, planetary and social boundaries have been added to the path of development, showing that decoupling and green growth might not be sufficient to reach the goal of environmentally sustainable development, if planetary boundaries have already been transgressed. In this case, in order to reach the ESD goal, a movement along the curve to the left is necessary, towards a sufficiency pathway, implying the need to decrease obsolescence and change consumer preferences. At lower development stages, at which planetary boundaries are not transgressed, a fully decoupled development with the highest possible resource efficiency should be pursued. Linked to the discussion about economic growth, this shows that an increase in QL is possible even under the condition of declining environmental pressures, but that degrowth in terms of the conventional GDP/cap must be allowed in certain cases.

Finally, the ESD model has been linked to an existing green growth model, enabling an interdisciplinary examination of issues concerning environment, society and economy. Furthermore, population size and density have been internalized as far as the planetary boundaries per capita are concerned, however, not yet as an endogenous variable to the ESD model. Furthermore, the model could be utilized to foster SDG prioritization, and to adopt environmentally differentiated CDM strategies.

5.2. Reflection & Outlook

As illustrated in the theory section, most existing models dealing with environmentally sustainable development are either extensions of existing growth models, adjustments of existing indices, or have a very specific scope. Adjusted growth models in the field of neoclassical macroeconomics, conceptualising environmental pressures mostly in the context of market failures or in the form of input factor limitations, are facing the issue of the imperfect GDP, which is yet to be resolved. Adjustments of specific indices (such as SHDI, HSDI, E-SHDI etc.) directly include certain environmental pressures or impacts, but have the disadvantage that they reduce the complex matter into one number, which does not tell anything about the relationship between environmental and societal factors. Models dealing with specific resource types have the advantage to be very precise, but cannot be easily fit into the bigger picture.

The ESD model presented in this thesis is of abstract-analytical nature. Important assumptions are a fair share approach and that quality of life is the ultimate goal of development. It has the advantage that the relationship between the two most relevant factors, quality of life as the goal of human development and environmental pressures as the limiting variable, is assessed; another advantage is that no adjustment of existing indicators is necessary. Furthermore, its general nature allows the inclusion of planetary boundaries as a physical aspect and social boundaries as a political aspect. Most importantly, the high degree of interdisciplinarity enables establishing a profound connection between physical ecological models and monetary neoclassical models, and so contributes to theoretically rethink decoupling and the degrowth debate.

The general nature of the model is also its most important limitation; compared to more resource-specific ecological models, it will be very difficult to parameterize all parts, and to make numerical predictions. This is particularly difficult for the questions, how quality of life can be measured and whether environmental pressures and impacts should be compiled into one composite footprint (in one single unit, which would make it even more abstract) or treated separately, requiring different models for each footprint. Furthermore, it could be regarded as too simplistic; in the view of the author, this drawback is outweighed by the high degree of connectivity, in particular the connection to green growth models.

Future research could aim at further validating the model as a whole, at parameterizing and refining its explanatory variables, and at adopting further extensions. Particularly, a profound review of the relationship between development indices, subjective indicators of well-being and GDP/cap could validate the ESD model. Additionally, a detailed, numerical analysis of concepts like circular economy, obsolescence, resource efficiency and sufficiency in the light of the propositions made in this thesis, but also connected to green growth models, could be a first step towards a new comprehensive model.

A promising approach for possible extensions could be an analysis comparing footprints (consumption-based) with production-based indicators, and with accumulated emissions and extractions. The relationship to production-based indicators could be utilized to further examine the development clusters and to highlight dependencies between world regions; accumulated emissions and extractions could help refining the connection to planetary boundaries, and to highlight historical responsibilities among all countries. Another extension necessary to make the model more comprehensive could be the internalization of population size and density, and of inequality. All these approaches should be pursued in an interdisciplinary way, as both classical and ecological economics, but also psychology, sociology and natural sciences are working on this strongly interlinked issue from different points of view.

Finally, I would like to recall the current environmental, societal and economic situation and its interdependencies with the academic world: After the two world wars of the 20th century, the economic growth paradigm was contributing to an era of economic growth and societal prosperity. Starting in the 1970s with the first report to the Club of Rome, scientists and media warned of environmental and social side effects of that development. Now that societal movements are claiming a transition from fossil to renewable energy carriers could be taken as a momentum changer, also within academia. Although, in my opinion, most conventional models are obsolete in their original forms and many alternative models have been developed, we are still lacking a new comprehensive standard model, including environment and society on the same level, acknowledged as the state of the art, and suitable to be taught in schools and universities. Therefore, I would like to encourage the academic world to engage in interdisciplinary modelling, contributing to an environmentally sustainable development to the highest possible quality of life.

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Annex Links & Navigation

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Annex 3: Data Collection

https://www.dropbox.com/s/pe6wjycup4zkrff/Annex%203%20-%20Data%20Collection.xlsx?dl=0

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