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Green, greener, grey

Disentangling different types of green growth

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1 Introduction

Green growth currently ranks high on policy agendas as it is perceived to be a crucial means to promote sustainable development. Accordingly, large efforts are devoted to the development of policy instruments as well as measurement tools in order to advance green growth and track its progress. However, the stakeholders involved are diverse and so are their green growth perceptions. In consequence, policies aiming to promote green growth differ not only in their structure but also with respect to what exactly they are aiming to achieve. By treating green growth as one overarching policy aim, there is a risk to gloss over the different goals. As a result, decisions may be distorted and misallocations of resources may become more likely. In this paper we therefore analyze how the impact of green policies depends on the underlying green growth concept.

With our paper, we propose a framework in which growth patterns can be subdivided into three categories based on their environmental impact. To this end, we first review different green growth concepts and extract their differences and commonalities in order to conceptualize green growth. Building on the existing literature, we propose three categories of growth, namely green, greener or grey: We thereby suggest to distinguish between growth that is ``good'' for the environment (or *green*), in the sense that it increases environmental quality or leaves stocks intact, and growth that is ``better'' (or *greener*) than a dirtier, counterfactual growth path, e.g. due to increased efficiency and, thus, fewer emissions per unit of production. *Green*, as presented here, is therefore understood as an absolute improvement, while *greener* can be seen as its relative counterpart. However, so far, both types of policies, either aiming at relative or absolute improvements, are being subsumed under the umbrella term of green growth, although the implications of setting these distinct policy goals can differ considerably. Following the literature, we use a production framework, and focus on the changes of inputs and outputs. The production process itself will not be modeled explicitly. Since green growth is understood as a subset of sustainable development, we address two major challenges of the sustainability debate, namely rebound effects and questions of substitutability of natural capital.

The results show that the change of the term green growth from applying to the growth of the eco-industry to the growth of the entire economy (Jänicke, 2012) is not as contradicting as it seems at first sight: Looking at policies that focus on conservation, clean-up, or protection/mitigation on the one hand and measures aiming to improve efficiency on the other, one can conclude that they do not have the same objective function and that they should not be treated in the same category, where they can potentially be traded-off against each other (subsidies into solar PV cannot compensate for filter systems or taxes on coal plants).

Based on the presented differentiation between green and greener growth it becomes apparent that many policies which were set about to promote green growth (in the overall sense), would not qualify as green within the proposed concept. They would be rather termed *greener* growth policies. The proposed explicit sub-categorization of the green concept may help to clarify the purpose and aim of specific government interventions. Depending on the underlying definition, the policy space alters and distinct instruments become feasible or desirable.

The article proceeds with an introduction into the main definitions of green growth and related concepts and discusses their core defining features. Based thereon, the production framework is introduced and the essential aspects of our definition of green growth are presented. Subsequently,

the distinction between green, greener, and grey growth is introduced and their defining features are explained. This is followed by a discussion of the implications from two main issues of the sustainability debate, namely rebound effects and the substitutability of different forms of capital, before we conclude.

2 Background

2.1 Green growth concepts

Green growth is a comparatively new concept which has become a kind of buzzword and gained widespread attention in recent years (Toman, 2012). It evolved from the *sustainable development* debate (Hallegatte *et al.,* 2011) which, broadly speaking, seeks to find a new paradigm of economic activity that counterbalances economic, environmental and social needs. Sustainable development was famously defined in the so-called Brundtland Report (Brundtland, 1987) and the discussion about how to create economic progress that is in accordance with environmental preservation and that fosters social inclusion then gained momentum following the 1992's International Conference on Environment and Development (UNCED or Rio-Conference).

Our discussion starts from the basic premise that economic growth, i.e. the accumulation of productive, man-made capital and the resulting increase in GDP, has contributed to higher income and consumption levels as well as to improvements in overall living standards (Barro and Sala-I-Martin, 1995) and generally spurred ancillary progress in educational attainment, health status or political voice – and vice versa (Aka and Dumont, 2008). Besides these indisputable merits, however, past developments have not come without costs. The heavy dependence on and exploitation of natural resources in order to foster industrialization and production has increased the pressure on natural resources. As a consequence of the ongoing exploitation of natural resources, environmental damages have become increasingly apparent (Brown *et al.,* 2013). Without adequate action, this detrimental trend will continue and eventually undermine the basis of economic activity and prosperity (Hallegatte *et al.,* 2011). Against this background, the green growth concept can be understood as a recalibration of economic and social progress in order to adhere to natural boundaries.

Even though green growth is currently put at the core of inter-/national policy agendas and a large amount of research is devoted to this new growth paradigm, the concept itself still lacks an unambiguous definition. Consequently, versatile issues are subsumed under this umbrella term. One potential reason for this lack of clarity is the heterogeneity of stakeholders and interests involved in the discussion. The Green Growth Knowledge Platform (GGKP, which comprises of around 30 member organizations among them the three initiating key green growth actors OECD, UNEP, World Bank), acknowledges for this plurality of perceptions and definitions and seeks to disentangle the current discussion (e.g. Green Growth Knowledge Platform, 2013). In particular, it intends to align the different perspectives and to close existing knowledge gaps in order to facilitate a further implementation of the approach.

Green growth is currently understood as a subset of sustainable development which particularly focuses on the reconciliation of the economic and environmental dimension (OECD, 2011). Hence, green growth does not surrogate for sustainable development but deliberately emphasizes its economic and environmental pillars and makes them a focal point of inter-/national development

planning and implementation (Huang and Quibria, 2013). In consequence, sustainable development can be understood as the ultimate objective, while green growth is merely the means to this goal (World Bank, 2012). Nevertheless, one should stress that the social dimension is not excluded from the approach. Instead, a thoughtful and profound incorporation of social concerns which i.a. encompass distributive issues is immanently important for acceptance (World Bank, 2012). However, the emphasis put on social considerations and the extent to which they are incorporated into respective green growth concepts differ decisively across distinct actors (UNDESA, 2012).

Additionally, the term green growth has shifted meaning in recent years: It has moved on from referring to the expansion of eco-industries to a comprehensive realignment of economic growth (Jänicke, 2012). The least common denominator for the heterogeneous set of different green growth perceptions, though, seems to be the claim of balancing economic and environmental objectives.

By and large, this fairly general description of the green growth approach is of minor controversy. But, as we will show in the following paragraphs, this leaves space for differing interpretations of the concept; implying the emphasis of distinct aspects and/or the pursuit of different aspirations. Apart from varying definitions of the concept itself, the discussion is additionally blurred by the introduction of various other terms that, for a large part, coincide with the concept but also exhibit decisive differences (UNDESA, 2012). In this sense, 'green development', 'low carbon development' or 'green economy' have to be regarded as other concepts which, nevertheless, can largely be used interchangeably (Toman, 2012; UNDESA, 2012; UNEP, 2011*b*; OECD and IEA, 2010). However, they emphasize different aspects and take different perceptions as well as objectives as a basis. Even though all approaches considered here have in common that they intend to alleviate the environmental impact of economic activity, some approaches still prioritize conventional GDP growth while others put larger emphasis on environmental preservation or human well-being, including social aspects and distributional issues. An extensive overview of distinct green growth, green economy and low carbon economy concepts is provided by UN DESA's *Guidebook to Green Growth* (2012). It presents various publications and national strategies and analyzes to which extent the three dimensions of sustainable development are incorporated into the respective definitions.

One major stream of thought within the current debate is associated with the OECD and World Bank approach. Green Growth, according to their perception, is economic growth that is characterized by an efficient use of resources, the minimization of pollution and environmental impacts, resilience to natural risks and the inclusion of marginalized groups (World Bank, 2012)**.** Hence, the conventional focus on economic growth and development remains. Nevertheless, it is extended by a special emphasis on resource efficiency, in order to ensure the provision of crucial environmental goods and services, and by concerns about social inclusion (OECD, 2011). Even though various other aspects are incorporated into the concept, GDP growth and a resource-efficient redesign of respective growth paths are of particular interest.

Taken literally, the preceding definition denotes every increase in GDP as green that relies on relatively fewer natural resources in the production of a single unit of output. Since the definition only refers to relative measures of environmental input-use (e.g. resource intensity of the GDP) and refrains from relating to absolute reference points for the environmental dimension (e.g. the level of a particular environmental indicator such as total GHG-emissions), strict abidance of the definition does not necessarily imply improved environmental conditions. Due to potential rebound effects, i.e. situations where the positive environmental effects of efficiency improvements are (partially) offset

by increased production and/or demand, the opposite might be true even if this definition of green growth was strictly adhered to.[4]

A similar focus on economic growth and resource efficiency can be found in other parts of the literature. Huang and Quibria (2013), for instance, define green growth as economic growth which avoids costly environmental degradation, unsustainable natural resource use as well as climate change and losses in biodiversity. While it is sometimes alleged that environmental protection imposes additional costs, the authors argue that an eco-friendly recalibration of growth processes does not necessarily imply a reduction of growth rates. Instead, it is merely an attempt to counterbalance short-term needs for economic growth and long-term needs for environmental sustainability. In particular, Hallegatte *et al. (*2011) argue that additional efficiency gains as well as innovation and knowledge spillovers, which result from intensified efforts to protect the environment, might provide additional growth stimuli (World Bank, 2012; Croitoru and Sarraf, 2010).

The green growth concepts presented so far are characterized by referring to relative measures of resource-efficiency and stressing the necessity to generate (short-term) GDP growth. This perception is based on the assumption that natural and manufactured capital are – to a certain extent – substitutable. Therefore, those concepts principally allow for a deteriorating environment – if accompanied corresponding investments in the physical and intangible capital stock – in order to increase national income.

Brock and Taylor (2005) also require increases in income in their definition of green growth (which they denote as sustainable development). However, in contrast to the previously presented approaches, they indirectly reject the possibility to (infinitely) substitute different forms of capital as they base their definition on an absolute environmental benchmark, when they define sustainable development as *a balanced growth path with a non-deteriorating or even increasing environmental quality and ongoing growth in income per capita*. Accordingly, efficiency improvements in input-use that bring along rebound effects and therefore result in a deterioration of certain environmental indicators are not in line with this green growth definition. Instead, the definition stresses the duality of economic and environmental objectives and the imperative to pursue them simultaneously.

Smulders *et al.* (2014) add to this discussion by distinguishing between long- and short-term green growth and thus combine parts of the above mentioned approaches. While their green growth definition requires continued growth in income/production with at least constant environmental quality and a non-deteriorating natural resources in the long-run, they allow for the substitution of different forms of capital and modest negative environmental impacts in the short-run (Smulders *et al.,* 2014).

Another distinctive feature of their definition compared to the previously presented approaches is that the authors explicitly start form a welfare perspective. Green growth is therefore rather

[4] While, in principle, it is acknowledged that a more resource-efficient recalibration of growth paths could induce an additional impetus on GDP growth, the World Bank explicitly states that green growth cannot be a panacea or substitute for good business environments and reforms to promote (economic) growth (World Bank, 2012). Rather it has to be perceived as a growth strategy with the additional goal of fostering a better environment (World Bank, 2012). Accordingly, green growth should not be understood as merely relying on environmental policies and measures to enhance resource and energy efficiency, but as a broader concept that integrates those means into an overall strategy to improve competitiveness.

understood as a holistic concept to maximize human well-being where environmental quality and the imperative to generate GDP growth constitute auxiliary conditions (Smulders *et al.,* 2014).

This welfare-centered approach, in contrast to the previously presented perspectives that put particular emphasis and focus on GDP growth, can be regarded as a second major stream of thought. It is mainly associated with the UNEP and its *green economy* concept. Improving human-wellbeing and social equity, while significantly reducing environmental risks and ecological scarcities, is at the heart of this alternative approach (UNEP, 2011*b)*. Economic growth still remains an important means to achieve the objective of improved well-being. However, concerns about absolute levels of environmental quality and resources as well as consideration about social equity are more prominent. Instead of focusing on the recalibration of economic growth paths under the auxiliary constraint of resource-efficiency, this alternative perception rather defines the single objective to maximize well-being subject to the triad of economic, environmental and social concerns (see also Jänicke, 2012).

In summary and as a preliminary result, various definitions of green growth have evolved and exist concurrently. While they put different emphasis on distinct features, all approaches have in common that they intend to mitigate the environmental impact of economic activity. However, decisive differences become apparent with regard to whether they refer to absolute or relative measures of improvements in resource use. Moreover, different 'shades of green' are covered, from concerns about greenhouse gas emissions solely, on the one hand, to larger critiques of the environmental sustainability of modern capitalism on the other hand (UNDESA, 2012; Huberty *et al.,* 2011).

Similar observations and conclusions have been drawn by other scoping papers. Jänicke (2012), for instance, analyzes the strategies presented by institutions like the OECD or EU commission and finds that strategies differ with respect to the extent to which they include elements of sustainable development. Drawn from empirical evidence, he concludes that up to now there has only been a relative decoupling[5] of economic growth and resource consumption in some high income countries. Yet, in order to avoid irreversible damages, an absolute decoupling or moderation of economic growth would be needed. In accordance to the differentiation of concepts presented above, Jänicke (2012) also concludes that the OECD strategy (and related literature) only integrates two of three pillars of sustainable development, namely economics and the environment, leaving out the social dimension. We agree that the contrasting UNEP approach provides a more comprehensive concept.

A broad number of concepts, which also encompass zero- and de-growth approaches, are compared by Gerd Ahlert et al. (2013). The authors map these approaches into a three-dimensional result space (*economic growth*, *social justice*, and *ecological viability*), which depicts the importance of each dimension for the respective growth concept. Concluding that most concepts are too simple to capture the complex interactions between economics, environment and society, they derive ten requirements a comprehensive sustainable welfare model should fulfill. Yet, the authors do not clearly distinct this model from the previously categorized (green growth) models, but rather collect very broad and general requirements for a national welfare concept.

[5] Decoupling refers to the relationship between economic growth and the corresponding evolution of environmental indicators, e.g. resource use. Relative decoupling is characterized by a decreasing resource use-to-GDP ratio, e.g. resource use increases with economic output but at a slower rate. In contrast, absolute decoupling relates to economic growth accompanied by a decrease in resource use (Smulders *et al.* 2014; UNEP, 2011*a*).

With regard to the differences between green growth concepts, Toman (2012) argues that green growth is either understood as a means to correct for existing externalities or as a strategy that produces additional benefits from potential synergies between long-term sustainability and short-term economic growth. Smulders *et al.* (2014) connect these differences in green growth perceptions to the sustainability debate: with reference to the distinction between strong and weak sustainability[6], they introduce the notion of "strong and weak green growth". They argue that the OECD view rather refers to "weak green growth" as it assumes the general existence of trade-offs, i.e. that environmental protection comes at the costs of decreased economic growth. Yet, these trade-offs might be tackled by appropriate policies. The "strong green growth" view, in contrast, is promoted by the UNEP's concept which emphasizes synergies and positive spillover-effects between economic growth and environment protection. This view embeds theories like the Porter hypothesis according to which environmental policies can actually enhance productivity and subsequently economic growth (Porter and van der Linde, 1995).[7]

2.2 Production framework

A suitable foundation for an analysis and categorization of green growth is a production framework which is presented as a somewhat natural starting point in GGKP (2013) and employed e.g. for the development of the OECD system of green growth indicators. The approach can be regarded as a simplified structure of the process of economic production, which is basically illustrated as a targeted transformation process that converts inputs into outputs. Figure 1 illustrates the framework, where the production framework is indicated by the dotted line.

Inputs are withdrawn from the asset base while outputs are either consumed, i.e. create well-being, or reinvested into the asset base, i.e. sustain or increase respective capital stocks. In contrast to the versatile literature on economic growth, which aims to specify and model production in a functional form, we treat the transformation process itself as a "black box". For our notion of green(er) growth the decisive aspects are the changes in inputs and outputs.

[6] The distinction between weak and strong sustainability is based on the possibility to substitute different forms of capital. While *weak sustainability* merely requires a non-decreasing stock of total capital and thus allows for the substitution of different forms of capital, *strong sustainability* necessitates non-declining natural capital.

[7] A more detailed discussion of the relationship between this differentiation and the distinction between green and greener growth is left for future research.

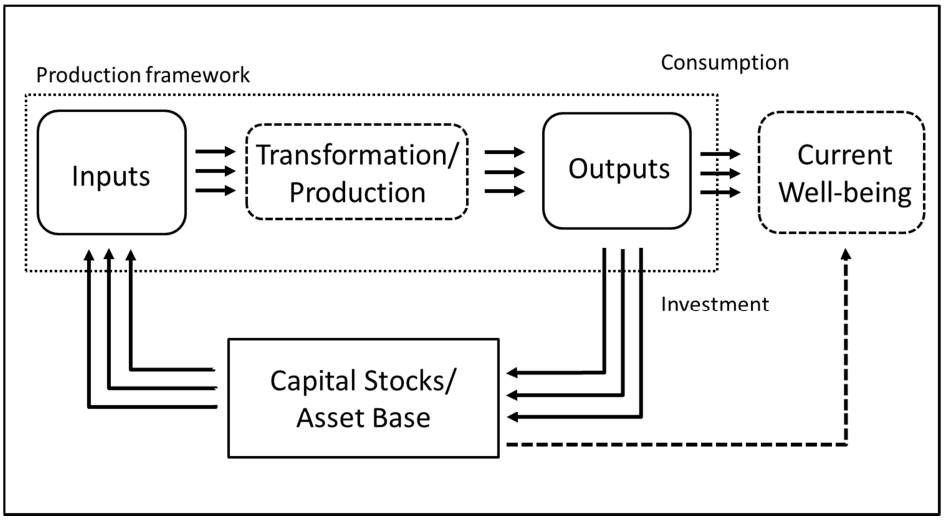

Figure 1: The production framework (based on GGKP, 2013)

Inputs to the production process are drawn from the available asset base. Following the World Bank's classification, a country's asset base consists of *manufactured capital* (e.g. machinery, equipment, infrastructure), *natural capital* (e.g. depletable as well as renewable natural resources, land, ecosystems and their services) or *intangible capital* (World Bank, 2006). The latter category can be further subdivided into *human capital* (e.g. size of the workforce, skills, knowledge) and *social capital* (e.g. governance, law enforcement, institutional quality, culture) (Hamilton and Hepburn, 2014))[8]. Capital, in general, is perceived to be any stock of tangible and intangible assets which facilitates the production of flows of goods and services (Ekins *et al.,* 2003) The aggregate of all capital forms constitutes an economy's comprehensive wealth (World Bank, 2006) which, in turn, determines the present value of a nation's (future) streams of income or wellbeing (Hamilton and Hepburn, 2014). To varying extents, all forms of capital are used within production and thus determine feasible output levels and, consequently, what people can consume or invest. While nature is a crucial input to the production process and decisively influences human well-being, economic theories often lack an adequate incorporation of natural resources and ecosystem services in their modelling framework (Karsten, 1987). The absence of well-functioning markets and prices for many environmental goods and services is one main reason for this under-representation, which is likely to lead to an underinvestment in the environment and a consequent depletion of natural resources along pathways of economic development.

Outputs of economic production not merely comprise desired economic goods and services but also encompass undesired by-products, such as greenhouse gas emissions or other externalities. Hence, within the logic of the production framework, outputs of the economic production process are not limited to the economic sphere but explicitly include aspects and determinants of environmental and intangible assets.[9] Production outputs can thus be interpreted as investments in or depreciations of particular capital stocks. While excess economic outputs generally add to the manufactured capital stock, excess environmental and social bads (e.g. degradation of ecosystems, deterioration of health conditions, or social unrest due to aggravated inequality) are likely to reduce the stocks of natural and intangible capital. This variation of capital stocks effectively constitutes a change in

[8] Some authors incorporate further categories such as net financial assets or intellectual property.
[9] Therefore, excess output, i.e. output which is not used for consumption or dissipated by environmental or social processes during the considered period of time, either adds to or deducts from respective capital stocks.

(comprehensive) wealth, which can be either positive or negative. This broader conception of production outputs and their impact on the entirety of capital stocks reflects the tree dimensions of sustainability.

In sum, we assume that economic production does not exclusively affect manufactured capital but (e.g. through its use of inputs) clearly also has an impact on environmental and intangible capital stocks. Obviously, this is particularly important in order to detect possible indicators capable of exhibiting the relationship between economic output and the environment. The OECD (2011, 2014), for instance, uses the framework in order to elicit the relationship between the natural asset base and economic activity (production, consumption, trade) while the affiliated Green Growth Knowledge Platform (2013) rather emphasizes the broader concept of comprehensive wealth and its contribution to output generation.

Within this paper, we use this approach as a reference framework, from which we draw the conclusion that that a definition of green growth (and related concepts) has to refer to the evolution of the asset base or to particular input or output variables which affect respective capital stocks.

3 Green, greener, grey: Propositions for a framework with two dimensions

In order to systematically present the idea of green(er) growth, it is necessary to define what is meant by *green* and by *growth*. It is useful to enter the discussion by first addressing the latter term. In this section, we use the term ***growth*** as economic growth,[10] i.e. referring to the relative increment in the manufactured capital stock and the production of goods and services over time, thereby abstracting from the third dimension of sustainable development.[11] We therefore proceed by categorizing green growth processes based on the developments of the economic and environmental dimension and their interaction.

To quantify economic growth, the most commonly used measure is gross domestic product (GDP) (Stiglitz *et al.,* 2009; OECD, 2011). In particular, the evolution of GDP per capita provides a rough proxy for individual well-being (derived from consumption) which is robust to demographic characteristics and therefore suitable for inter-temporal as well as cross-country comparison.[12] In accordance with Brock's and Taylor's (2005) sustainable growth definition, one defining feature of green growth is therefore an ongoing increase in income per capita. As a consequence of this requirement, development processes which exhibit zero or negative per capita growth rates do not match the concept at hand and are therefore deliberately neglected; even if they result in a

[10] The Green Growth Knowledge Platform (2013) suggests a classification into factors *to sustain*, which contain environmental indicators, and factors *to develop*, which comprise economic as well as components of intangible capital such as education or health. This could be incorporated in our framework in a next step, i.e. the economic dimension would then be equivalent to the dimension "to develop" comprising of economic as well as intangible capital. This would position our concept closer to the second group of concepts presented in section 2.1.

[11] In principle it would be desirable to include all three dimensions, but for the distinction between green and greener, it does not seem to be likely to alter the results.

[12] For a discussion see e.g. Stiglitz *et al.* (2009), Enquete-Kommission Wachstum, Wohlstand, Lebensqualität (2013),or World Bank (2006).

sustainable redesign of economic production in a sense that current levels of production and well-being can be maintained and that environmental preservation is ensured.[13]

If growth refers to the economic dimension and if GDP is used as a convenient measure, several issues evolve concerning the appropriateness of the employed indicator. GDP constitutes by far the most common measure of economic activity albeit one of the concerns when using it as a measure of economic activity evolves from being a gross measure. Even if it is accompanied by complementary environmental indicators it still neglects the depreciation of manufactured capital and therefore remains incomplete. Therefore, net measures like net national income have been proposed as a substitute or complement for GDP. Nevertheless, GDP will most likely remain – at least in the foreseeable future – the central variable for the macro-economic development and economic activity (OECD, 2011).

For the sake of balancing preciseness and scope in this exercise, we suggest that the growth component of the green growth concept requires a positive growth rate of per capita production:

> ***Proposition 1:*** ***Green growth*** *requires positive growth rates in economic output per capita and the manufactured capital stock.*

The term ***green*** refers to the evolution of the environmental dimension. We argue that green growth requires a non-deterioration of natural capital stocks and associated ecosystem goods and services.[14] This perception is largely in accordance with the sustainable development definition presented by Brock and Taylor (2005) and is based on absolute instead of relative points of reference. This, for instance, necessitates tracking the development of forest stocks or freshwater resources as well as the available stock of minerals or arable land such as proposed by the OECD's set of measures of the natural asset base (OECD, 2011). However, it is not merely the stock, quality or size of natural resources that is of importance, but also the amount and quality of derived ecosystem goods and services which are derived from natural production processes.

> ***Proposition 2:*** ***Green growth*** *requires a non-negative evolution of the natural capital stock and derived ecosystem goods and services.*[15]

Growth patterns that compromise environmental assets and as such oppose (absolute) green growth are called ***grey*** growth. Grey growth therefore denotes economic output growth which is accompanied by a deterioration of the natural asset base and a consequent decline of respective ecosystem goods and services.

> ***Proposition 3:*** ***Grey growth*** *constitutes positive economic growth entailing a decline of natural capital and/or derived ecosystem goods and services.*

[13] Alternative approaches such as zero- and de-growth concepts are discussed within the academic and societal discourse evolving from sustainability. Per definition, they are not considered within the present paper.

[14] Ecosystem goods and services, among other things, determine the economic value humans derive from ecosystem. The Economics of Ecosystems and Biodiversity (TEEB) report distinguishes between provisioning, regulating, cultural and supporting services (for further reading see TEEB (2010)).

[15] This definition once again shows the importance of assumptions on the substitutability of different forms of capital for each other, when (virtually) non-renewable natural capital stocks are considered.

Since a reduction in the value of the natural capital stock simultaneously impairs the capacity of nature to contribute to future production and well-being, grey growth appears to be less desirable compared to its counterpart. However, in the short-run, or rather under circumstances where natural capital is relatively abundant, substituting natural capital with manufactured and human capital can increase current as well as prospective well-being (see also section 2.1). Indeed, Hamilton and Hartwick (2014) demonstrate that positive net (genuine) savings facilitate the sustained extension of wealth. The development of high-income countries, in fact, was largely based on the transformation of natural assets and the simultaneous increase of the total capital stock (Hamilton and Hepburn, 2014). Consequently, grey growth is not necessarily detrimental to human well-being; at least as long as it remains transitory and does not pass certain environmental thresholds.[16] Consequently, while some transformation of natural capital is desirable, optimality – at least with regard to the transformation/depletion of some natural assets – might already be surpassed (Helm, 2014).

The definition of green and grey growth presented above is based on the impact economic growth has on absolute environmental measures, namely the natural capital stock. Both terms can either be used for entire development pathways, taking a *long-term* perspective on whether respective growth trajectories will eventually decline the stock of natural capital or not, or to *short-term* developments, referring to the evolution of natural capital during a defined period of time (e.g. one calendar year or legislative period).[17]

We therefore propose ***greener*** growth as a third category, which is based on relative measures such as resource intensity (or its reciprocal, i.e. resource productivity). Greener growth is thus a comparative concept: A specific growth path can only be greener than a (counterfactual) alternative. It has to exhibit a lower resource intensity or a higher resource productivity in order to be denoted as greener. The greener growth concept applies to green as well as grey growth paths and can be interpreted as a subcategory of both development patterns. It is thus possible that greener growth is accompanied by absolute reductions of the natural capital stock.

> ***Proposition 4:* Greener growth** *requires a relative improvement in the productivity of natural capital.*

4 Implications

If put into context with the general debate, the preceding analysis shows the necessity to distinguish between absolute and relative green growth concepts since they can refer to decisively different environmental developments. Based on the presented categorization of growth patterns, only a fraction of “green growth” concepts presented in paragraph 2 comply with the definition developed within this paper. The majority, tough, would rather fall into the proposed category of greener growth.

[16] However, a continued reduction of the natural capital stocks eventually results in environmental scarcities which imperil and limit the substitutability of natural resources and ecosystem goods and services within economic production and (direct) creation of well-being.

[17] This is closely related to the discussion in Smulders *et al.* (2014) presented in section2.1.

The introduction of greener growth as an additional concept is thus useful in order to demonstrate that countries which produce negative environmental outcomes but simultaneously improve their relative impact, still require additional effort in order to accomplish sustainability but, nevertheless, have initiated positive processes that can eventually lead to this end. Making this additional classification enables a more accurate differentiation of development processes than a mere distinction between green and grey growth. It can therefore help to address critical issues, e.g. whether further progress in resource-use-, energy- or pollution- intensity is required, without losing the absolute dimension of green growth).

Returning to the initially presented production framework, it becomes obvious that the presented concepts also differ significantly with regard to respective leverage points for measurement. Green and grey growth can be conceived as output-centered approaches. Their definitions – according to the present paper – are based on the development of output indicators as well as the evolution of capital stocks. Greener growth, in contrast, refers to the economic output dimension but additionally looks at inputs for the environmental sphere. It therefore does not provide a measure how natural capital evolves over time but it indicates how environmental inputs are used in order to produce a certain level of output.

Besides all differences in the definition and implications of green and greener growth, both concepts also exhibit commonalities. In particular, both growth patterns imply that the degradation of natural capital per unit of GDP decreases for positive economic growth. For growth to be green, the size of the decrease of respective intensity measures has to be large enough to outweigh the negative scale effect of economic growth. This, however, is not necessarily true for greener growth processes. Based on this perspective, our concept is closely related to absolute and relative decoupling (see e.g. Smulders *et al.* (2014) for the case of emissions). Absolute decoupling means that emissions per unit of GDP are reduced at least at a rate equal to the growth of GDP. Relative decoupling, in contrast, describes a case in which the emissions-to-GDP ratio is reduced at a slower rate than GDP rises. In both cases emission intensity is reduced, but in the latter case not enough to compensate the scale-effect of GDP growth. In our concept, this translates into the rate of (total) natural capital reductions and not only emissions. This is in line with other parts of the literature (e.g. Jackson, 2009 or UNEP, 2011*a*), who also advocate a broader perspective and refer to ecological or resource impacts.

In the following section the implications of green and greener growth are briefly discussed for two central issues of the sustainability debate, namely rebound effects and substitutability.

5 Discussion: Implications of green(er) growth for sustainable development

In this section two issues that are crucial in the debate of a transition from grey growth to green growth are discussed, namely rebound effects and substitutability between different forms of capital. The potential occurrence of rebound effects determines whether or not environmental efficiency improvements result in green or greener growth, while the degree of substitutability influences the possibilities to enhance environmental efficiency in production and affects the assessment of the aggregated natural capital stock (detached from single components) and thereby constitutes the necessity of the green growth concepts. As green(er) growth is considered a means to

achieving sustainable development, it is not surprising that both issues have also been central to the sustainability debate. Generally, rebound effects, substitution possibilities and, closely related to them, technical change determine the effectiveness of environmental policies (Smulders *et al.,* 2014). Therefore, first rebound effects and then substitutability are discussed against the background of our green(er) growth conceptions.

5.1 Green(er) growth and rebound effects

The preceding section closed with linking green and greener growth to absolute and relative decoupling, i.e. an economy's capacity to grow without aggravating environmental pressures (UNEP, 2011*a*). Both concepts therefore coincide to a large extend and merely differ with regard to how manufactured and intangible capital are included into the definition of growth[18]. The green and greener growth concepts generally take a broader perspective and expand the notion of growth beyond the sheer expansion of economic output production.

Irrespective of the definitional peculiarities, though, decoupling as well as green and greener growth face a common challenge: attempts to promote sustainable development are frequently accompanied by the renowned *rebound effec*t (Santarius, 2012; Gillingham *et al.,* 2014; Sorrell, 2007; etc.). The term, in general, describes the phenomenon that theoretically possible/ predicted reductions in energy-use due to increased energy efficiency[19] are, at least partially, offset by consumer and market responses (Gillingham *et al.,* 2014). Usually, the rebound effect is calculated as the percentage of projected energy reductions which were not realized; i.e. the effective loss of savings potentials due to market reactions (Gillingham *et al,.* 2014). In extreme cases, the rebound effect can exceed 100 percent, implying that energy-/resource-use is intensified compared to the initial situation. This phenomenon is also known as *backfire* or the *Kazzhoom-Brookes postulate* (e.g. (Santarius, 2012; Saunders, 1992). There are various mechanisms which can contribute to the rebound effect (Sorrell, 2007; Santarius, 2012); Gillingham *et al.,* 2014). In particular, energy efficiency improvements can change relative prices and real income and, thus, evoke substitution and income effects. For instance, increase energy efficiency reduces both, production costs as well as energy prices. In turn, consumers perceive a gain in real income which can increase the consumption of energy (direct effect) as well as other products (indirect effect). At the same time, reduced costs for energy producers can result in reinvestments and an expansion of production capacities, increased demand for other energy-intensive inputs and so on. A by far more detailed examination of various rebound effects is provided by Santarius (2012), Jenkins *et al.* (2011), Paech (2011) or van den Bergh (2011).

Rebound effects, depending on their extent, inflict significant challenges on the initiation and maintenance of sustainable development processes as they reduce or even negate positive impacts on the environment. Policies that are primarily targeted at efficiency improvements in order to realign economic growth with environmental preservation might eventually fail to prevent resource depletion (Santarius, 2012). Rebound effects, with regard to the proposed distinction between green and greener growth, are of particular importance for the latter concept.

[18] Furthermore, differences also exist with regard to the conceptual scope. While decoupling merely describes the process of detaching economic output growth from environmental impacts, green growth (in a general understanding) comprises the entire strategic framework and set of instruments to achieve this end.

[19] The same also holds for improvements in resource-use efficiency and respective changes in resource consumption.

As alleged within this paper, *green growth* development pathways per definition require non-deteriorating environmental indicators. Hence, potential rebound effects would have to be anticipated and thwarted by appropriate measures. This constitutes a necessary requirement of the concept itself, regardless of whether it explicitly accounts for rebound effects it eventually accounts for their environmental implication. In contrast, *greener growth* policies are focused on relative energy and resource-use efficiency improvements, disregarding any changes in measures of environmental resources and quality. Those two peculiarities, however, make this concept particularly prone to the impact of rebound effects. One the one hand, the greener growth concept further those measures that facilitate the emergence of rebound effects while, on the other hand, no mandatory monitoring of potential environmental impacts is claimed. Hence, implementation of sheer greener growth policy measures might induce rebound effects, which could countervail or even negate the positive environmental implications of efficiency improvements. Even if rebound effects are smaller than 100% and they therefore "only" reduce the savings potential of efficiency improvements, they still matter in a growing economy. Due to scale effects (Brock and Taylor, 2005) economic growth is commonly accompanied by expanded resource and energy inputs. If technological progress, i.e. efficiency improvements, cannot keep pace with growth-induced increases in input use, decoupling becomes infeasible. Depending on the pace of growth and the extent of realized efficiency improvements, the existence of rebound effects might then limit or even prevent the possibility of green growth and sustainable development. A neglect of potential rebound effects is one of the reasons why many policies intended (or labeled) to be green, are really "only" greener.

The variety of presented green growth concepts in section 2.1 demonstrates the particular concern about energy-, pollution- or resource-use intensity during the process of economic production. While improving intensity measures is necessary in order to achieve green growth and sustainable development, it is most likely not sufficient. As long as the reduction of intensity measures does not outweigh the impact of economic growth, the strain on environmental resources will continue to tighten (Smulders *et al.,* 2014)[20]. To the perspective taken within this paper, this will not be consistent with green growth. Growth patterns along which efficiency measures are improved but where the overall impact on the environment remains negative still match the defining characteristics of grey growth. Nevertheless, if efficiency improvements gradually decrease the absolute negative impact on the environment, growth can be considered to become greener.

5.2 Green(er) growth and substitutability

An aim of sustainable development is the at least maintenance of current utility levels for future generations. Hence, the ability of the underlying assets, i.e. capital stocks, to provide a certain amount of utility has to be sustained. This does not necessarily mean that each capital stock hast to be maintained completely. The substitutability of capital forms with regard to production and providing utility is an intensely discussed issue which resulted in the distinction between the weak and the strong sustainability view. The weak sustainability view aims at preserving the aggregated sum of all sorts of capital since it assumes that factor substitution between forms of capital is generally possible. Hence, consumption can be maintained through factor substitution if a form of

[20] Brock and Taylor (2005) illustrate that the environmental impact of economic activity is based on the size of production, the structure of production and the technology applied within production. Even if an economy manages to move towards cleaner industries and technologies, expected positive environmental impacts can be offset by the scale of economic output growth (Smulders *et al.,* 2014)

capital becomes scarce. A prominent example within this strand of literature is the Hartwick Rule, which states that the scarcity-rents of exhaustible resources depletion should be reinvested in human-made capital to sustain future consumption (Hartwick, 1977). It is based on a Cobb-Douglas production function that entails a factor substitution elasticity of one. The strong sustainability view assumes only limited substitution possibilities between the forms of capital, e.g. substitution elasticities less than one. Therefore, a sufficient amount of each capital stock has to be preserved separately in order to ensure future production (Costanza and Daly, 1992; Pearce and Turner, 1990; Turner, 1993).

It is an ongoing debate if or to what extent natural capital and its services can be substituted through produced or intangible capital. The neoclassical production theory assumes near to perfect substitutability while "ecological economists" like Daly advocate that natural and produced capital are complements with very limited substitution possibilities (Costanza *et al.,* 1997). Cleveland *et al.,* (1996) state that the degree of substitutability is generally determined by technical conditions (e.g. resource endowments or the ease of substitution among inputs) and institutional conditions (e.g. like market structure and property right systems). Under current technological possibilities it is obvious that various components of natural capital or the services they provide cannot be substituted. Several limits might always remain existent. Non-substitutable natural capital that provides essential functions for production and welfare is labeled "essential" (Dasgupta and Heal, 1979) or "critical natural capital" (Ekins *et al.,* 2003).[21] The issue of substitutability also plays a role within capital stocks. When trying to aggregate single components of natural capital to a total natural capita stock, essential components theoretically should be evaluated separately since their services cannot be replaced by increases of other forms of natural capital. In contrast, e.g. non-renewable energy forms might be allowed to be depleted if a sufficient stock of renewable energy forms is build-up to substitute the decline, so that in total the stock of natural capital or better its resulting services remain constant (Costanza and Daly 1992). Hence, substitution possibilities within natural capital forms, be it between input factors or components of the utility function, determine whether changes in the aggregated natural capital stock can be transferred to according changes in production and utility possibilities or not. In many cases substitution is possible and technological progress might further enhance substitution capabilities in the future. There are a number of studies that investigate the complex issue of natural capital substitutability empirically (e.g. Markandya and Pedroso-Galinato, 2005).

Ideally, threatened natural capital should be substituted through produced or intangible capital in the production process, so that the natural capital stock and its amount of services can be maintained. Yet, often a substitution through a less scarce or less harmful form of natural capital is more realistic or the only possibility. Cleveland *et al.* (1996) distinguish between two general types of substitution, substitution within and between categories of input factors. The substitution of non-renewable natural capital through renewable natural capital or lignite through the relatively cleaner[22] natural gas is beneficial in environmental terms even though it is a substitution within the natural capital stock. Applied to our framework, a substitution of lignite through natural gas in

[21] As Mäler (2007) notes, the distinction between weak and strong sustainability is to a certain extend an artificial one, as not many people advocate for any of the two as a "pure doctrine". Instead, qualifiers and combination of the concepts (such as e.g. weak sustainable development with thresholds) are used widely.

[22] In terms of CO2 emissions

electricity production would be greener growth, while a substitution through renewable energies would mean green growth ceteris paribus (no other changes in consumption and production). In the case of strong sustainability, green growth policies are required to preserve the natural capital stock.

Environmental policies should encourage the best possible substitution. Green and greener growth both require the resource and pollution intensity of production to fall. Substitution is one way to achieve these goals. This might be less difficult in the long-term than in the transition phase. A lot of obstacles like technology lock-ins only occur in the short-term; scale-effects and technological progress might also reduce costs of substitutes in the long-term. Developing countries might generally have more financial constrains to invest in alternative technologies, but on the other hand, they might not be as locked-in in dirty technologies as developed countries. In any case, a policy that also promotes growth e.g. via reduced resource-dependencies from other countries is easier to enforce. Finally, policies should encourage research and development to create substitution possibilities for critical natural capital.

6 Summary and conclusions

The present paper compares different green growth concepts as proposed by a number of international organizations and from the economic literature. We show that there are various perceptions subsumed under the same umbrella term, possibly caused by the multitude of stakeholders involved in the green growth debate. The green growth definitions discussed range from focusing on the improvement of intensity measures (e.g. emissions, or energy-intensity) to requiring absolute environmental improvements. We find that they differ even more with regard to the third dimension of sustainability, i.e. the social dimension, which is sometimes the main objective and in other cases excluded altogether.[23] Additionally, the term green growth has shifted meaning from referring to the expansion of eco-industries to a comprehensive realignment of economic growth. The lowest common denominator between the definitions reviewed seems to be that the relationship between the economy and the environment is addressed.

Based on these results we propose to divide green growth into two categories, termed green and greener. Green growth refers to development that simultaneously generates positive increases on the (economic) and environmental output dimension of a production framework. Grey growth on the other hand describes economic growth that is accompanied by a deterioration of the environment. In order to clarify our approach we abstract from including the social dimension explicitly and focus on the co-evolution of the economic and the environmental dimension.[24] Greener growth refers to economic growth with relative improvements in the environmental dimension, i.e. it is compared to a counterfactual growth trajectory. Greener growth can, in principle, be green or grey.

[23] These large differences can be explained by the diversity of stakeholders using the term and contexts it is used in, e.g. if the concept is to be directly applied in policy processes (and therefore has to include distributive concerns and to provide inclusive solutions) or if the aim is to add to the knowledge of the interaction between economic and environmental factors. There are thus decisive differences in the working definitions of green growth concerning the scale of how social concerns are incorporated.

[24] While we refrained from integrating social/intangible aspects into the green(er) growth concept, it should in principle be possible to extend the concept to include all three forms of capital.

The proposed distinction makes it possible to reflect the differences between concepts that address relative improvements in the environmental dimension and those that require absolute improvements. As such, the distinction between both growth patterns becomes especially important in the long-rung (i.e. when natural capital becomes scarcer) as the maintenance of (at least) a minimum level of natural capital is required.

Greener growth is (economic) growth that is more efficient in the use of natural resources and therefore depicts lower intensity measures (e.g. energy intensity, emissions intensity, etc.) compared to counterfactual growth trajectories. This means that the (negative) environmental impact of greener growth patterns are lower compared respective counterfactuals or, if a specific growth path is examined over time, that respective intensity measures decrease with time so that the impact per unit of output is reduced. This perspective is of particular practical relevance and is congruent with several existing green growth definitions. The reason why the present paper proposes a distinct term for this form of growth is that greener growth patterns merely indicate improvements in the use or resources but neglect the overall impact on the environment. As long as those improvements cannot outweigh the impact of increased production, the economy continues to rely on natural resource depletion and will eventually approach and transgress environmental boundaries. Considering this, denoting such growth trajectories as green would be misleading. By contrast, denoting these growth paths as grey omits to acknowledge realized efficiency improvements and reduced relative impacts which are essential to achieve green growth and sustainable development.

The introduction of green, greener and grey growth as three distinct growth categories thus provides some useful insights and helps to disentangle current ambiguities. The distinction between green and grey growth indicates whether present production patterns can be sustained in the long-run or not and, therefore, if a general rethinking of economic production will be necessary. The greener growth concept, on the other hand, depicts whether currently employed measures actually lead to a relative reduction of environmental impacts and, thus, if initiated transformation processes are on track. On the one hand, this simple classification provides an unambiguous way to pinpoint at required policy steps. On the other hand, it helps to clearly formulate policy targets and decide on suitable instruments.

Discussing implications of the proposed greene(er) growth concept regarding the substitutability of different forms of capital, we find that, in line with the claim of the established strong sustainability approach, green growth necessitates a non-declining natural capital stock and therefore requires the substitution of environmental inputs within production. Since the definition of greener growth is based on efficiency and intensity measures, it only requires a relative substitution of natural capital within production, i.e. environmental inputs have to growth at a slower pace than economic output. Naturally, the green(er) growth concept is closely connected to the weak/strong sustainability debate.

Rebound effects, which describe the phenomenon that theoretically positive environmental impacts of efficiency gains are (partially) offset by production and consumption effects, are particularly relevant for greener growth policies. Since respective policies merely focus on efficiency gains and principally leave other developments unattended, they provide no safeguard against potentially detrimental implication. In contrast, green growth policies generally are thought to consider a wider spectrum of policy implications since they have to consider how natural capital changes over time.

Hence, even though this does not entirely prevent the rebound effects, this might help to mitigate them as these developments would have to be taken into account explicitly.

In sum, in order to initiate sustainable development and mitigate the impact of economic production on the environment, countries will have to formulate specific targets they want to achieve – either in absolute or in relative terms. Policies which concentrate on efficiency gains would be deemed greener growth policies and will result in the reduction of the environmental impact per unit of economic output. If efficiency gains are not able to compensate for rebound and growth effects, natural capital stocks and corresponding ecosystem services will continue to decline. It will depend on available technologies whether such a decline can be substituted in the long-run.

An example of a typical greener growth policy would be the claim for a specific reduction of the emissions intensity within the manufacturing sector. Respective policy instruments could make the installation of filters mandatory or support R&D within the sector. By contrast, green growth policies would formulate an absolute target, such the reduction of emissions within the manufacturing sector by X tons per annum. Under the assumption that these reductions are not based on scale effects, i.e. a decline in production, respective measures have to be implemented. On the one hand, this can be efficiency improvements of existing technologies that are large enough to achieve the required absolute improvement – same policy instruments can be applied as for greener growth targets. On the other hand, policies could also mandate the switch towards alternative technologies. This shows that depending on whether countries strive for green or greener growth will change the set of available policies and respective instruments which they can apply.

While policy measures can be aimed at green or greener growth or at both simultaneously, only the conceptual distinction makes their goals explicit and thus visible. It hence allows for a better tailoring of measures, and can potentially prevent certain (undesirable) trade-offs. Before deciding on a specific policy one should therefore formulate clear aims of that policy, i.e. explicitly state if the policy in question pursues green or greener growth or both. When separate green budgets are suggested, these should explicitly state which part addresses green and which part promotes greener growth.

In the end, opting for green or greener growth paths remains a political decision based on normative judgments. But stating the goals explicitly by using the distinction between green and greener growth could support a more transparent debate about policy aims and subsequently help to better target green(er) policy outcomes.

8 References

Aka, B.F. and J.C. Dumont (2008). 'Health, education and economic growth: Testing for long-run relationships and causal links', *Applied econometrics and international development* vol. 8(2), pp. 101–10.

Barro, R.J. and X. Sala-I-Martin (1995). *Economic growth*, New York NY u.a: McGraw-Hill.

Brock, W.A. and M.S. Taylor (2005). 'Economic Growth and the Environment: A Review of Theory and Empirics'.

Brown, J.H., J.R. Burger, W.R. Burnside, M. Chang, A.D. Davidson, T.S. Fristoe et al. (2013). 'Macroecology meets macroeconomics: Resource scarcity and global sustainabilit', *Ecological Engineering*.

Brundtland, G.H. (1987). *Report of the World Commission on Environment and Development: Our Common Future*, [New York]: [United Nations].

Cleveland, C.J., R. Ayres, B. Castaneda, R. Costanza, E.H. Daly, C. Folke et al. (1996). 'Natural Capital, Human-Made Capital, Economic Growth, and Sustainability'.

Costanza, R., C.J. Cleveland and C. Perrings (1997). *The Development of an Ecological Economics*: Edward Elgar.

Costanza, R. and H.E. Daly (1992). 'Natural Capital and Sustainable Development', *Conservation Biology* vol. 6(1), pp. 37–46.

Croitoru, L. and M. Sarraf (2010). *The Cost of Envrionmental Degradation: Case Studies from the Middle East and North Africa*, Washington, D.C.

Dasgupta, P.S. and G.M. Heal (1979). *Economic Theory and Exhaustible Resources*: Cambridge University Press.

Ekins, P., S. Simon, L. Deutsch, C. Folke and R. de Groot (2003). 'A framework for the practical application of the concepts of critical natural capital and strong sustainability', *Ecological Economics* vol. 44(2-3), pp. 165–85.

Enquete-Kommission Wachstum, Wohlstand, Lebensqualität (2013). *Schlussbericht der Enquete-Kommission "Wachstum, Wohlstand, Lebensqualität - Wege zu nachhaltigem Wirtschaften und gesellschaftlichem Fortschritt in der Sozialen Marktwirtschaft": Deutscher Bundestag, 17. Wahlperiode ; Drucksache 17/13300*, Berlin: Dt. Bundestag.

Gillingham, K., D. Rapson and G. Wagner (2014). 'The Rebound Effect and Energy Efficiency Policy'.

Green Growth Knowledge Platform (2013). 'Moving towards a Common Approach on Green Growth Indicators', *Green Growth Knowledge Platform Scoping Paper*.

Hallegatte, S., G. Heal, M. Fay and D. Treguer (2011). 'From Growth to Green Growth', *World Bank Policy Research*.

Hamilton, K. and J. Hartwick (2014). 'Wealth and sustainability', *Oxford Review of Economic Policy* 30 (1), pp. 170–87.

Hamilton, K. and C. Hepburn (2014). 'Wealth', *Oxford Review of Economic Policy* vol. 30(1), pp. 1–20.

Hartwick, J.M. (1977). 'Intergenerational Equity and the Investing of Rents from Exhaustible Resources', *American Economic Review* vol. 67(5).

Helm, D. (2014). 'Taking natural capital seriously', *Oxford Review of Economic Policy* vol. 30(1), pp. 109–25.

Huang, Y. and M.G. Quibria (2013). 'Green growth: theory and evidence', *WIDER Working Paper No. 2013/056*.

Huberty, M., H. Gao, J. Mandell and J. Zysman (2011). 'Shaping the Green Growth Economy: A review of the public debate and the prospects for green growth'.

Jackson, T. (2009). *Prosperity without growth: Economics for a finite planet*, London, New York: Earthscan.

Jänicke, M. (2012). '"Green growth": From a growing eco-industry to economic sustainability', *Energy Policy* vol. 48, pp. 13–21.

Jenkins, J., T. Nordhaus and M. Shellenberger (2011). *Energy Emergence: Rebound and Backfire as Emergent Phenomena*, Oakland.

Karsten, S.G. (1987). 'Nature in Economic Theories: Hans Immler Traces Recognition of the Environment. And Its Neglect. In Various Classics', *American Journal of Economics and Sociology* vol. 46(1), pp. 61–70.

Mäler, K.-G. (2007). 'Wealth and sustainable development: the role of David Pearce', *Environmental and Resource Economics* vol. 37(1), pp. 63–75.

Markandya, A. and S. Pedroso-Galinato (2005). *How substitutable is natural capital?*, Washington, DC: World Bank.

OECD (2011). 'Towards Green Growth', OECD Green Growth Studies.

OECD and IEA (2010). 'Low-Emission Development Strategies: Technical, Institutional and Policy Lessons' (last accessed: 30 September 2014).

Paech, N. (2011). 'Grünes Wachstum? Vom Fehlschlagen jeglicher Entkoppelungsbemühungen: Ein Trauerspiel in mehreren Akten', in: Ökonomie der Nachhaltigkeit. Grundlagen, Indikatoren, Strategien, Marburg.

Pearce, D.W. and R.K. Turner (1990). *Economics of Natural Resources and the Environment*, Baltimore: Johns Hopkins University Press.

Porter, M.E. and van der Linde, Claas (1995). 'Toward a New Conception of the Environment-Competitiveness Relationship', *The Journal of Economic Perspectives* vol. 9(4).

Santarius, T. (2012). 'Green Growth Unravelled: How rebound effects baffle sustainability targets when the economy keeps growing'.

Saunders, H.D. (1992). 'The Khazzoom-Brookes Postulate and Neoclassical Growth', *The Energy Journal* vol. 13(4), pp. 131–48.

Smulders, S., M. Toman and C. Withagen (2014). 'Growth Theory and "Green Growth"', *OxCarre Research Paper*.

Sorrell, S. (2007). *The Rebound effect: An assessment of the evidence for economy-wide energy savings from improved energy efficiency*, Sussex: UK Energy Research Centre.

Stiglitz, J.E., A. Sen and J.-P. Fitoussi (2009). 'Report by the Commission on the Measurement of Economic Performance and Social Progress', http://www.stiglitz-sen-fitoussi.fr/documents/rapport_anglais.pdf.

TEEB (2010). 'The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations', London and Washington.

Toman, M. (2012). 'Green Growth: An Exploratory Review', *World Bank Policy Research*.

Turner, R.K., ed. (1993). *Sustainable environmental economics and management: Principles and practice*, London u.a: Belhaven Press [u.a.].

UNDESA (2012). *A Guidebook to the Green Economy: Issue 1: Green Economy, Green Growth, and Low Carbon Development - history, definitions and a guide to recent publications*: United Nations Division for Sustainable Development.

UNEP (2011*a*). *Decoupling Natural Resource Use and Environmental Impacts from Economic Growth*, [Paris?]: United Nations Environment Programme.

UNEP (2011*b*). *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*.

van den Bergh, Jeroen (2011). *Industrial energy conservation, rebound effects and public policy*, Vienna: United Nations Industrial Development Organization.

World Bank (2006). *Where is the Wealth of Nations? Measuring Capital for the 21st Century*: The World Bank.

World Bank (2012). 'Inclusive Green Growth: The Pathway to Sustainable Development', Washington, D.C, https://openknowledge.worldbank.org/handle/10986/6058.

Annex: A graphical approach to green(er) growth

Figure 2 attempts to clarify the distinction between the presented concepts graphically. Starting from reference point A, which can be though to depict a country's current situation – with Y_A[25] being (economic) value of its composite stock (incl. the size of production, the stock of manufactured capital as well as specific components of the intangible capital stock) and E_A representing its natural capital stock (incl. respective ecosystem services) –, any movement to a point B within the upper-right quadrant corresponds to green growth since both dimensions are increased simultaneously ($Y_B > Y_A$ and $E_B > E_A$). Grey growth, by contrast, is represented by movements towards any point C within the upper-left quadrant ($Y_C > Y_A$ but $E_C < E_A$.). Developments which result in a decline of the composite measure Y may be denoted negative growth and, accordingly, are not considered within this paper.

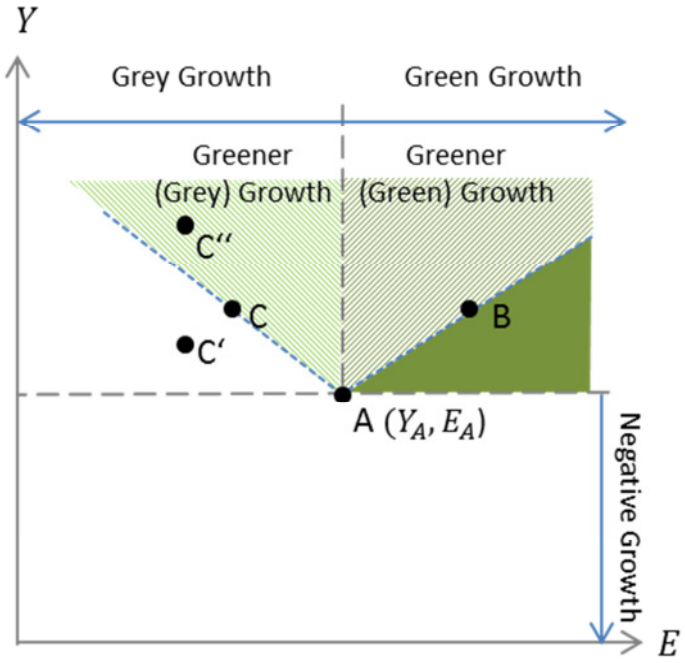

Figure 2: Graphical representation of green, greener, and grey growth[26]

While the distinction between green and grey growth is straightforward, greener growth requires a more detailed explanation. As was argued before, greener growth is a relative concept – which is a result of two separate features: First, greener growth is based on the comparison of two distinct growth paths and therefore requires scrutinizing parameter changes of two separate developments. Comparisons could be made for a single country, e.g. by scrutinizing how respective parameters have evolved during past periods of time or by elaborating potential future implications of different policy option. Likewise, it is also possible to conduct a cross-country analysis and compare the growth

[25] For reasons of simplicity we assume a constant population size. Accordingly, we can abstract from a per capita perspective without a loss of generality.

[26] Figure 2 depicts the concepts of green, greener, and grey growth only for a single country or for two identical countries, which exhibit identical initial values for the compound and natural capital measure. This allows comparing only the changes of intensity measures. For two distinct countries, examining relative changes in those measures would be required.

trajectories of different economies. Second, the definition of greener growth is based on intensity measures and, thus, relates resource or energy inputs to a comprehensive output measure – e.g. resource-use per unit of output. Accordingly, the second reason for the relative nature of the concept is caused by the properties of employed parameters. These two peculiarities have to be kept in mind in order to understand how greener growth is depicted in Figure 2.

We already mentioned that a movement from A to C ($\overline{AC}$) represents grey growth as $\Delta Y_{\overline{AC}} = Y_C - Y_A > 0$ while $\Delta E_{\overline{AC}} = E_C - E_A < 0$.[27] For the purpose of illustrating the greener growth concept, we compare this growth trajectory with two alternative patterns; here:$\overline{AC'}$ and $\overline{AC''}$, respectively. Both growth paths entail the same negative environmental impact which is stronger compared to a movement to point C; i.e. $|\Delta E_{\overline{AC}'}| = |\Delta E_{\overline{AC}''}| > |\Delta E_{\overline{AC}}|$. Since $\overline{AC'}$and $\overline{AC''}$ are more extractive in absolute values and, accordingly, lead to a larger depletion of natural resources, it might be intuitive to denote growth path $\overline{AC}$ as *greener*. However, this conclusion neglects that the definition of greener growth is based on measures of resource-use intensity – or their reciprocals, i.e. measures of natural capital productivity. For the depicted case, we therefore have to investigate the different evolution of the intensity measure.$\Delta E/\Delta Y$. The relationship describes how many environmental resources, in net terms, were required in order to increase the compound output variable Y which is equivalent to the reciprocal of the slop of the dotted line $\overline{AC}$. This leads to the following ordering: $|(\Delta E_{\overline{AC}'}/\Delta Y_{\overline{AC}'})| > |(\Delta E_{\overline{AC}}/\Delta Y_{\overline{AC}})| > |(\Delta E_{\overline{AC}''}/\Delta Y_{\overline{AC}''})|$. Hence, while the growth pattern of $\overline{AC}'$exhibits the largest resource intensity (lowest resource productivity), growth corresponding to $\overline{AC}''$ displays the most efficient use of nature within production of the three alternatives. $\overline{AC}$ only represents an intermediate performance. This analysis shows that any growth path that leads the economy to a point within the greenly hatched triangle above the extended $\overline{AC}$-line corresponds to growth that is deemed to be greener compared to the $\overline{AC}$-growth pattern. Ceteris paribus, a mere reduction of resource depletion or a mere increase of growth rates leads to a greener grey growth path.

In principle, the same line of reasoning also holds for the comparison of different green growth paths.[28] In order to detect which growth path is perceived to be greener, we compare the respective resource intensity ($\Delta E/\Delta Y$) or productivity. Growth paths which exhibit larger values again would be denoted as greener. Accordingly, for the comparison of $\overline{AB}$ with alternative growth patterns, the dotted blue line with a slope of $\Delta Y_{\overline{AB}}/\Delta E_{\overline{AB}}$ provides the corresponding threshold. Based on the presented definition of greener growth, only points above this line are deemed to be greener. This finding might again lead to a counterintuitive result: given a certain rate of growth in Y, larger increases of E are not regarded as greener. This is again a result of the specific definition of greener growth which refers to measures of resource intensity or productivity. Implicitly, this implies a primacy of growth concerns above environmental issues since assessing whether a certain green growth paths is greener compared to an alternative merely depends on the growth of Y, ceteris paribus.

[27] In the following, growth paths, e.g. the movement from one point A to point C, will be indicated by an upper bar is indicated by a bar. The respective quantitative changes in parameters will be indicated by a Δ-sign.

[28] While it is possible to find greener growth paths within each of the two main growth categories, i.e. green and grey growth, it is not possible to compare two growth paths of different categories since the interpretation of ΔE changes. The dashed vertical line is therefore a bound for comparability.

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