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Redefining Green Growth within Planetary Boundaries

By Per Espen Stoknes and Johan Rockström

ABSTRACT
Over the last decade, green growth policies have drawn increasing interest. OECD, UNEP, the World Bank and the EC have had several initiatives on the issue, and the Nordic countries have a special program on it. Definitions and indicator sets have been developed, though critics have pointed out that most initiatives amount to little more than a greenwashing of conventional economic growth. The paper proposes and discusses two definitions of green growth, one weak and one strong. Both build on resource- and carbon productivity measures, but whereas the weak definition requires absolute decoupling, the strong or "genuine green growth" requires sufficient decoupling to achieve science based targets for planetary boundaries. The approach is tested at country levels, starting with the climate boundary, by analyzing progress on carbon productivity ("CAPRO") in Nordic countries since 2000. Results show that so far, among Nordic countries, Sweden, Finland and Denmark have achieved genuine green growth, while Norway has not. Implications for policy and communication of green growth are discussed.

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1. Introduction: Defining Green Growth in a Verifiable Way

This paper's research question is two-pronged: What is "genuine green growth" – and to what extent can it be found in the Nordic countries? A natural starting point is to review and clarify some main definitions of 'green growth' proposed by intergovernmental bodies.

The Organisation for Economic Co-operation and Development, OECD, defines green growth as being "about fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. It is also about fostering investment and innovation, which will underpin sustained growth and give rise to new economic opportunities" (OECD, 2011, p. 18). The World Bank writes: "Green growth is growth that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental impacts, and resilient in that it accounts for natural hazards" (World Bank, 2012, p. 2). The European Commission, EC, writes that, "The aim is to **create more value** while **using fewer**

resources, and substituting them with more environmentally favorable choices wherever possible" (European Commission, 2016).

The United Nations Environmental Program, UNEP, defines a green economy as one that results in "improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities." The word "significantly" is not clarified, but UNEP continues to say that "a green economy is low carbon, resource-efficient, and socially *inclusive.*" UNEP does not distinguish clearly between "green economy" and "green growth". UNEP states that "In a green economy, growth in income and employment should be driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services" (UNEP, 2011, p. 16).

These definitions all say something about the intended direction of green growth (environmentally friendly and socially inclusive). Yet, none of the above have given a definition that sets measurable criteria for what passes as green growth. There is a lack of clear, simple indicators of whether economic growth at different scales - from cities, nations to the world, is "green enough" to enable economies to evolve within the biophysical safe operating space of planetary boundaries. The latter requires science-based targets for stable Earth systems. Below we define this as "genuine green growth". To relate a certain economic development to measurable, physical boundaries is essential for assessing whether it is genuine green growth or simply "pale green" or "greenwashing".

Due to this vagueness, many critics claim that "green growth" rhetoric often aims primarily at incrementally better efficiency and somewhat more sustainable consumption and production, but still disregards ecological limits from ecosystem to the Earth system (Anderson and Bows-Larkin, 2013; Dale et al., 2016; D'Alisa et al., 2014; Ferguson, 2015; Hayden, 2014; Jackson, 2011; Lorek and Spangenberg, 2014; Santarius, 2012; Spash, 2014). Therefore it becomes in practice mostly a continuation of the conventional economic growth model but just under a new label.

We argue for a transition from a "green growth" paradigm that essentially focuses on relative efficiency improvements to a "genuine green growth" paradigm that delivers absolute reductions in environmental impacts. Mounting scientific evidence shows that humanity is now the dominating force of change at the Earth system scale. We envision future economies that can thrive within physical planetary boundaries as a natural and necessary development of economic paradigms in the advent of the Anthropocene (Crutzen, 2002; Waters et al., 2016). In this new context we propose a genuine green growth model that incorporates defined global budgets of, e.g., carbon, nitrogen, phosphorus, land, minerals, freshwater. One novelty of the current paper lies in linking concepts that governments and political economists are already very used to – such as value added, consumption – with physical flow accounts that highlight the connection of these economic activities to planetary boundaries.

Building on decoupling theory (Grand, 2016; Tapio, 2005), we propose the following, simpler definition of 'green growth': *Green growth is an increase in economic output that lowers total environmental footprint.* "Economic output" is best understood as value added in an entity over a time period. "Total environmental footprint" can be operationalized in a number of ways; such as

CO_2 emissions in tons per year (pa), in material flows in tons pa, or by ecological footprint (EF) measured as global hectares pa (Wackernagel et al., 1999). In principle, any material resource use directly relating to (a set of) the planetary boundary dimensions that have been transgressed beyond the safe operating space for humanity (Rockström et al., 2009; Steffen et al., 2015) can be included.

This definition can then be used to define green growth with precision. Let "ΔGDP" mean annual percentage change in real gross domestic product for a country. Annual resource productivity (RP) is measured in value added divided by physical units; i.e. in dollars/tons, dollars/kWh, or dollars/EF measured in global hectares (Wackernagel, 2014). Let "ΔRP" be the resource-productivity as the year-on-year percent change in real GDP/environmental resource use. Then the *definition of green growth is given by the inequality:*

$$(1)\quad \Delta RP > \Delta GDP$$

To illustrate: If Sweden sees a GDP growth of 2% pa, and its carbon productivity improves by 4% pa, the country displays green growth in the climate dimension. The economy grows larger in real inflation-adjusted terms, while at the same time generating a ~2% less annual greenhouse gas (GHG) emissions. Green growth therefore relates to the rate of change in resource productivity relative to the overall growth rate of the economy. There is green growth when there is absolute decoupling of GDP growth from resource use: the economy grows while emissions fall.

"Gray growth" contrasts with green growth; gray growth can be defined as an *increase in economic output that also increases the total environmental footprint*. Here the environmental footprint grows in spite of a somewhat improved resource productivity. Each new car may have a somewhat more efficient combustion engine, but since more cars are produced and/or drive even more, the total environmental footprint from this economic output still goes up. This is similar to the "rebound effect," or "Jevon's paradox," that has characterized much of the economic growth model throughout the 20th century (Saunders, 2000; Sorrell, 2009). Using the same variables as above, we get: *Gray growth is*

$$(2)\quad \Delta RP < \Delta GDP.$$

To illustrate: Norway has a GDP growth of 2% in one year, and yet their resource productivity only improves by 1%. A 2% larger economy that uses resources 1% more effectively will *increase* its total environmental footprint with a ~1% pa. In such gray growth, the volume of the economic output growth eats up all the resource efficiency gains: the economy grows along with a (smaller) growth in emissions.

Accordingly – as critics of green growth, such as those referenced above point out – many politicians publicly proclaim to work for green growth and a green economy. But this often equates with mainly *talking* about reducing climate emissions and other environmental impacts, while simultaneously pushing for as much conventional economic and job growth as possible. Consequently, what is labeled as green growth in practice becomes gray growth, a continuation of the 20th century growth model, such as in the illustration with Norway.

To avoid such greenwashing one must directly link all economic activities to their environmental impacts in a measurable and consistent way and invest in sufficient resource productivity over time. Otherwise, as politicians and governments continue to talk about green growth while delivering gray growth, more critics become firmly negative to any prospects of green growth, and – in the face of disruptive climate change – want to stop economic growth altogether. Instead, they claim that our developed society must aim for degrowth (D'Alisa et al., 2014; Kallis, 2011; Kallis et al., 2012; Schneider et al., 2010).

Many scientists, climate activists and even some politicians often call for immediate cuts and large reductions of society's carbon emissions in absolute terms, to be achieved for instance by stringent regulations or higher carbon pricing. Unfortunately, these calls generate widespread resistance from many citizens, vested interests and policy makers, even if clearly needed from a climate science point of view (Stoknes, 2015). To become more effective in gaining public support for a economic transition that take planetary boundaries into account, one could rather than reinforce the perceived cut-and-degrowth framing (Anderson and Bows-Larkin, 2013; D'Alisa et al., 2014; Kallis et al., 2012; van den Bergh and Kallis, 2012), promote the green growth framing. This latter promises a more psychologically supportive win-win frame for engaging a broader public audience rather than the degrowth cut- and loss frame (Bowen and Fankhauser, 2011; Jänicke, 2012). Loss framings tend to psychologically generate more aversion and resistance among the general public, lowering support for climate policies (Antal and Van Den Bergh, 2014; Kahneman, 2013; Marshall, 2014; Stoknes, 2014; Tversky and Kahneman, 1991).

Critically though, if adopting a win-win green growth framing, the approach must be credibly linked to science-based targets. Without being credibly configured to attain economic growth within planetary boundaries over time, claims of green growth will lose validity and legitimacy. In this context even the above (1) definition of green growth may be too weak since the decoupling rate may not be sufficient: The global economy possibly requires a stronger, i.e. genuine version of green growth to take planetary boundaries fully into account.

To attain genuine green growth in the climate dimension the economic challenge is, then, how to break down the remaining global carbon budget (Greaker et al., 2013; Meinshausen et al., 2009; Peters et al., 2015; van Vuuren et al., 2016) to a fair and clear share for each nation state, city, industry and corporation without removing the new economic growth opportunities, particularly from poorer economies. One promising way of doing that is with a simple, but positive and dynamic indicator of carbon productivity, to be introduced below.

In section 2, this article will argue how to link carbon productivity with science based targets, as a first attempt to develop a genuine green growth methodology. In section 3 we apply the method on the Nordic countries, since Nordic societies are widely perceived to be one of the leading green growth regions (Dual Citizen LLC, 2014). Section 4 discusses the dynamics of and common objections to the indicator, while section 5 summarizes some policy conclusions and recommendations, particularly with respect to communicating green growth.

2 – How to Link Green Growth with Science-based Targets?

2.1 Prioritizing among green growth indicators

Among already established green growth indicator sets, carbon productivity (or its inverse carbon intensity) often gets a high priority (European Environment Agency, 2016; Global Commission on the Economy and Climate, 2015, 2014; OECD, 2014). This is no surprise given that the climate change problem is one of the foremost among the planetary boundaries that humanity has already transgressed (Jouvet and de Perthuis, 2013, p. 46; Rockström et al., 2009; Steffen et al., 2015). For a shift toward a green economy, a reduction of carbon emissions through better carbon productivity is a first, necessary measure, even if insufficient alone. We also need science based targets and indicators for green growth for biodiversity, land, water, pollutants and chemical entities, nutrient loading (nitrogen and phosphorus) as well as for social dimensions such as innovation, poverty alleviation and social justice. Yet, carbon productivity is a good starting point, due to its relative ease of measurement, as well as the urgency of further climate disruptions that would also severely worsen other environmental and social impacts, such as biodiversity, deforestation, agriculture, emigration, access to clean air and water (Schellnhuber et al., 2012).

Starting with climate emissions, this means that to earn the label of "genuine green growth" the carbon productivity of an economic entity must achieve a trajectory over time sufficient to meet science-based targets (CDP, UN Global Compact, WRI and WWF, 2016; Krabbe et al., 2015) derived from planetary boundaries (Steffen et al., 2015). Economic actors cannot (or should not) make up their own green growth targets on a whim (such as "Achieve a 25% reduction of CO_2 per unit of revenue by 2025" or "a 40% reduction by 2030"), and still claim to represent genuine green growth unless these targets actually align themselves with one or more of the science-based targets. For instance, while OECD publishes an entire set of green growth indicators (OECD, 2017, 2014), this organization does not provide any guidance as to what rate of change can be viewed as sufficient, i.e. *genuine* green growth. Based on the OECD's work, one can only rank the countries relative to each other, but not judge which of them has a satisfactory progress relative to planetary boundaries, and which may merely be the least bad of a possibly dismal cohort. OECD does not, in other words, explicitly link green growth to required carbon productivity rates.

2.2 Reviewing studies of required annual carbon productivity rates

The second step in this section is to review available studies on what the required rate of carbon productivity is for achieving the <2°C target to global warming. Carbon productivity is one core aspect of the overall resource productivity. In the following *CAPRO means the carbon productivity of an economic entity measured as the percentage change per year in real value added / tons of CO_{2e} emissions*. CAPRO is the inverse of carbon intensity, CI, (CAPRO=1/CI). Even if productivity and intensity measures are mathematically equivalent mirror images, we prefer carbon productivity over carbon intensity for communication and psychological reasons, to be discussed below.

To estimate CAPRO one needs measurements of both value added and carbon emissions from the same scope. At national level the value added is measured by the Gross Domestic Product (GDP). In spite of all the criticism against GDP and its well-known statistical limitations (Coyle, 2015; Stiglitz et al., 2009) it can still be useful for green growth policies as an indicator of overall activity level. In this article, we do not argue for or against GDP, but take a pragmatic approach to policy processes and societal change. The coming decade(s) are critical for shifting the economy towards staying within planetary boundaries. In this period, it is highly likely that GDP will continue to be one of the dominant national metrics in practical use.

Historically, global GDP – or rather the Gross World Product (GWP) – has on average grown at approximately 3% annually in recent decades (Akimoto et al., 2014; Tani, 2016). OECD, Europe, the Americas and Africa have recently tended to be below 3%, while Asia has recently been higher. Moreover, real GWP growth is down from approximately 5% pa in the 1960s, when productivity increases in developed nations were higher. This is largely due to greater productivity potential in improving agriculture and manufacturing at the time, relative to productivity improvements in the services sectors, which now make up about two-thirds of Western economies' GDP (Coyle, 2015). Moving forward, the year-on-year change in real GDP tends to decline as countries get richer (Gordon, 2016; Pritchett and Summers, 2014; Randers, 2016, 2012a; World Bank and Commission on Growth and Development, 2008).

Measurements of carbon emissions are also statistically demanding and estimates of the remaining carbon budget often disputed. More recent estimates of the remaining global carbon budget for a > 66% probability of staying below 2 °C range from approximately 600 - 1200 $GtCO_2$ (Rogelj et al., 2016). With current annual emissions of approximately 40 $GtCO_2$/yr, this indicates the need for mitigation pathways that globally reduce emissions by > 2 % per year, i.e., a halving of emissions 2015 - 2050, if relying on the higher end of the allowable carbon budget estimates. If using the lower estimate of the remaining carbon budget then > 6 % reduction per year is needed, resulting in approximately 5 Gt CO_2/yr remaining emissions in 2050. Importantly, the entire range of allowable carbon budgets depend on the necessity of bending the global curve of emissions soonest possible and no later than 2020. The wide range in estimates of remaining carbon budgets is largely explained by different assumptions in socio-economic pathways (SSPs), levels of probability of succeeding, and assumptions on carbon capture and storage during the second half of this century.

2.3 Carbon productivity "consensus" emerging

Several reports and studies have published estimates of the needed rate of carbon productivity improvement to achieve the 2^{o}C target (Kriegler et al., 2013; New Climate Economy Report, 2014; Randers, 2012b; UNEP, 2011). Among them, Antal and van den Bergh (Antal and Van Den Bergh, 2014) calculated the required yearly improvement in carbon productivity to be at least 4.4% pa. Randers (Randers, 2012b) calculated the minimum necessary carbon productivity to be 5% pa. *The New Climate Economy Report* writes that "the carbon productivity of the world economy (defined in terms of US$ of world output/tons of GHG emissions) would need to increase by about 3-4% pa until 2030. In 2030–2050 the improvement in carbon productivity would need to accelerate again, to around 6-7% pa, to stay on track" (New Climate Economy Report, 2014, p. 23).

The Deep Decarbonization Pathways project has chosen a model where the decarbonization rate (i.e. the carbon intensity of GDP) improves in steps per decade from a 2% pa in 2010-2020, a 3.4% pa in 2020-2030, a 5% pa in 2030-2040 and a whopping 8.5% pa in 2040-2050 (Deep Decarbonization Pathways Project, 2015 Figure 8). The average is again close to a 5% pa, even if the curve to 2050 has a different shape than those mentioned above.

Other authors have claimed that higher rates than 5% pa are needed. PriceWaterhouseCoopers (PwC) has calculated an average rate of a 6.3% decarbonization of GDP every year up to 2100 in order to stay within the 2^{o}C target without any negative emissions technologies toward the end of century (PriceWaterhouseCoopers, 2015). A study by Rockström et al. suggests a "Carbon Law" of 6-7% CO_{2e} reductions pa, which would mean 8-10% pa carbon productivity rate starting in 2020 to have a more than 50% chance of reaching a 1.5^{o}C target (Rockström et al, 2017). The book *Prosperity Without Growth*, by Tim Jackson, "wins" by calculating the highest rate, which is claimed to be a 9-11% pa (Jackson, 2011). This is partly because his target emission value for 2050 is a low 4 Gt for CO_2, hence producing cumulative emissions with a high probability of staying below 2C warming while also reducing the need for negative emission technologies.

For an overview of the different estimates identified – using somewhat different assumption models and methodologies – see Table 1:

Table 1: Overview of studies of annual improvement rates in carbon productivity/intensity needed to achieve <2^{o}C target

Author	Published	start year	end year	Goal	min. carb prod rate to 2050	Ref
Jackson	2009	2010	2050	450 ppm with >3.6% GWP pa	9-11%	loc 1625 , Fig 5.6
Randers	2012	2010	2050	>50% cut by 2050	5%	p. 49
Kriegler et al.	2013	2010	2040	450 ppm	~5%	Refpol450-scenario, Fig. 2
Akimoto et al.	2014	2005	2050	-50% by 2050	>4%	p. 251
Antal, van d Bergh	2014	2013	2050	-81% in GHG intensity	4.4%	p. 2
NCER	2014	2015	2050	-16% GHG 2030, -50% by 2050	3.5% to 2030, 6.5% to 2050	p. 23
NCER	2015	2015	2050	<2^{o}C	nearly 5%	p.6
PwC	2015	2010	2100	RCP2.6, <990GtCO2 carbon budget	6.3 %	p. 1
DeepDecarb Pathways	2015	2010	2050	-42%–57% GHG by 2050	2%, 3.4%, 5%, 8% per decade	p. 14, Figure 8
van Vuuren	2016	2010	2050	>50% chance <2000 $GtCO_2$ 2010-2100	4-6%	p. 6, Figure 3c

Based on the estimates in Table 1, as well as the economic growth rates in coming decades, this study will apply an average of a 5% carbon productivity annual rate as the minimum threshold value. *We can then define genuine green growth as:*

(3) CAPRO > 5%,

And since CAPRO is a core component of the broader ΔRP, a more general, parallel *definition of genuine green growth can be tentatively given as*:

(4) ΔRP > 5%

Five percent seems to be a pretty robust figure: despite variations in the studies' approaches, most studies converge near that number. Notwithstanding these studies, this actually follow directly from an average 3% GWP growth and the requirement to reduce global emissions by at least 2% pa, if relying on the higher end of the allowable carbon budget. It is important to recognize that this five percent level is very likely an optimistic, minimum rate of CAPRO.

Thus, if a country has only a 4% annual rate of carbon productivity improvement, its emissions decoupling may be relative (if it grows its GDP at >4%) or absolute (if GDP <4%). In any case, it does not have a sufficient improvement in carbon productivity to deserve the label "genuine green growth." Even if there is a (small, say, 1%) absolute emissions decoupling which qualifies for green growth according to definition (1), this is still not sufficient because it does not improve carbon productivity as required for the <2^{o}C climate planetary boundary.

3 – Green Growth in the Nordic Countries Since 2000, and Compared to Largest Countries

3.1 The sample of countries

In order to see whether genuine green growth can be empirically found in recent data, a study was done of the Nordic countries' carbon productivity since 2000. The main Nordic countries are Denmark, Sweden, Finland, Norway. All are OECD members.

The OECD database of green growth indicators, OECD Stat (2017), has annual data on Nordic countries from 2000 to 2014. It gives figures of production-based CO_2 productivity in GDP per unit of energy-related CO_2 emissions, denominated in 2010 US dollars per kilogram CO_2 (OECD, 2016). For this study, the first four years of the century, 2000-2003, were chosen as a baseline for comparison in order to study whether we can see genuine green growth in the following decade. The carbon productivity numbers were then converted to an index, where the average of the 2000-2003 period for each country was 100, see Figure 1 (Data points are in table 2 in appendix). The countries are then analyzed and compared relative to their annual change rate in carbon productivity, CAPRO, in the 11 following years for which there are available data, i.e. 2004-2014. The curve "GGG" shows the ideal genuine green growth requirement of at least a 5% pa improvement, based on the convergence of estimates of carbon productivity requirements above (Table 1).

3.2 Results: green growth annual change rate 2004-2014 for Nordic countries

The results in Figure 1 show that Sweden, Finland and Denmark have demonstrated genuine green growth in this century. However, Norway lags behind the others, performing lower than the OECD average with regard to carbon productivity. Using ordinary least squares, we have fitted a logistic growth curve to the development in the carbon productivity for the countries. Results for the 2003-2014 period show that Sweden has 5.76%, Finland 5.45%, Denmark 5.03%, Norway 1.47% and OECD-total 2.27% pa.

[Figure-1]

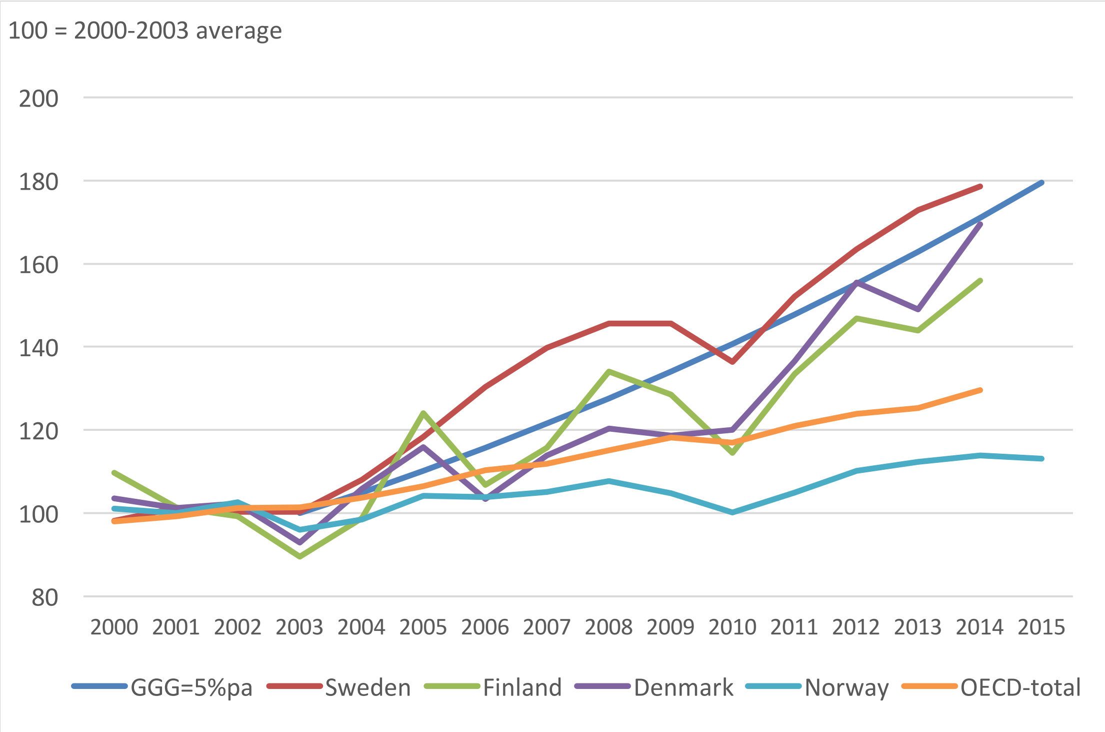

Figure 1: Genuine Green Growth in the Nordics, compared to the necessary 5% pa improvement in carbon productivity. Baseline 100=average 2000-2003. GGG=5% carbon productivity pa from 2003. Source: OECD Stats, Green Growth Indicators for 2000-2014, Production-based CO_2 productivity, GDP per unit of energy-related CO_2 emissions, US 2010 dollars per kilogram. Norway 2015 from Statistics Norway preliminary figures.

A frequent claim held by green growth critics is that there is no historic evidence of genuine green growth (Anderson and Bows-Larkin, 2013; Jackson, 2011; Lorek and Spangenberg, 2014). This claim can now be refuted with reference to a majority of the Nordic countries. In the 2003-2014 period, starting from the 2000-2003 baseline, Sweden, Finland and Denmark all have on average exceeded the 5% carbon productivity pa threshold, even if Denmark just barely. Norway, however, whose territorial emissions include the emissions from its offshore oil and gas production, is lagging severely behind.

Another source for data on the same countries over the same period is the database GlobalCarbonAtlas, which builds on data from UN statistics for GDP data and CDIAC, UNFCCC and BP for total CO_2 emissions (Global Carbon Project, 2016). Using the same approach to visualize the green growth for 2003-2014 yields very similar results, see Figure 2. Sweden's results are a slightly weaker in this dataset, though not significantly, while Denmark's are a slightly stronger. Figure 2 thus overall verifies the findings from the OECD dataset.

[Figure-2]

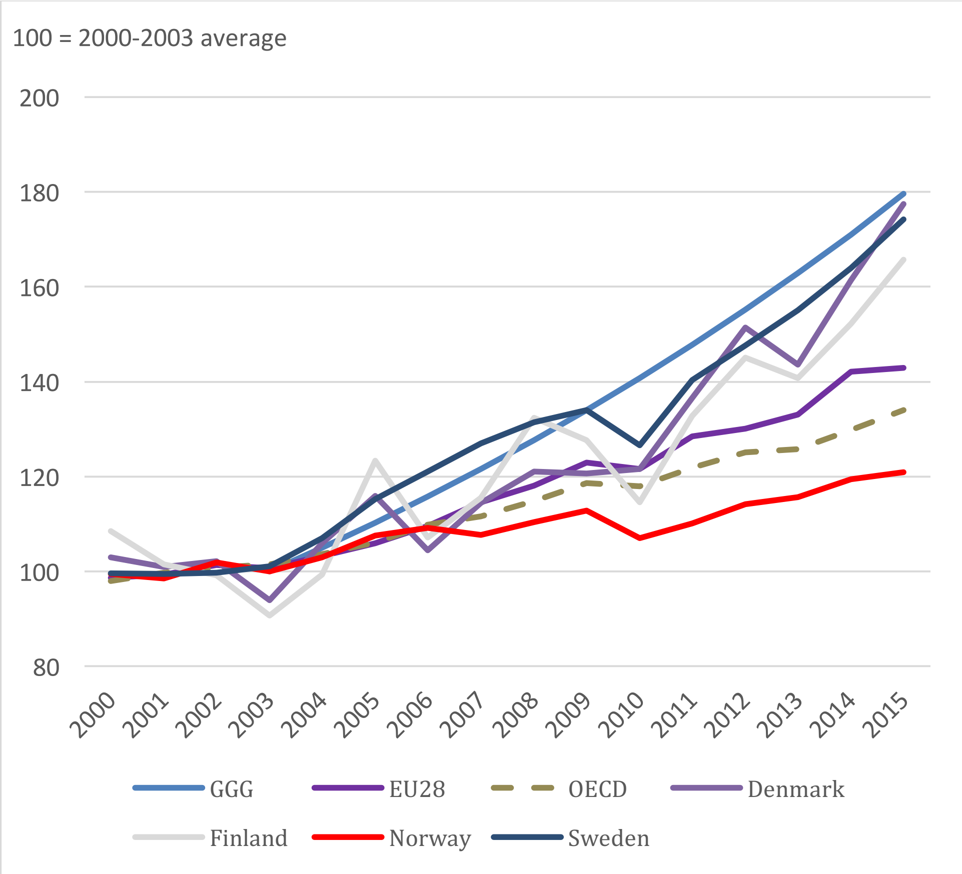

Figure 2: Genuine Green Growth in Nordics, 100= 2000-2003 average GGG= genuine green growth rate of 5% pa. Data source: GlobalCarbonAtlas from UN statistics for GDP data in PPP USD and CDIAC, UNFCCC and BP for CO_2 emissions.

3.3 Drivers and policies for green growth in the Nordics

What underlies the differences between the Nordics and other groups, such as the EU28 and the OECD average? Is their performance replicable by other countries? Studies that examine the Nordics' green growth performance have pointed to a number of drivers behind the development (Björk et al., 2016; Nordicway, 2016; Skjelvik et al., 2011). For example, in recent decades all four countries have accelerated a structural shift in jobs and value creation from industry and manufacturing to service sectors that are less emission intensive, including information, communication, high-tech and knowledge jobs (PriceWaterhouseCoopers, 2013; Skjelvik et al., 2011).

Sweden has since 2000 upheld a strong focus on energy efficiency and renewables, including the phase-out of oil for heating in the residential sector. A carbon tax on fossil-fuels, introduced in

1991 (oscillating on average at 100 USD/ton CO2), turned biomass into the most competitive fuel for heating, which further decarbonized the country's fuel mix. Sweden also has an ongoing action plan with a higher ambition for the renewable electricity certificate system, with an increase of 25 TWh in new capacity by 2020 compared to 2002 (IEA, 2013a, p. 13; PriceWaterhouseCoopers, 2013, p. 43). It is also seeing a strong growth of value added in its ICT sector, with many highly innovative companies (Blomquist, 2015).

Denmark has decarbonized its economy by using wind energy and natural gas, instead of coal and oil, and increased energy efficiency through district heating and combined heat and power (CHP). Denmark also stimulated the growth of renewable energy and energy efficiency industries by investing in R&D and creating a domestic market for energy technologies, particularly in relation to wind. These new industries are also estimated to add 1.6% to GVA and 1.5% to employment in Denmark. The stimulation of a domestic market for renewable energy is reflected in the energy prices and, more specifically, in the relative high energy tax burden for consumers (PriceWaterhouseCoopers, 2013, pp. 9–11).

Based on its "Climate and Energy Strategy" of 2008, Finland decided to improve energy intensity and the share of renewables to 38% of final energy consumption by 2020. Government has promoted biofuels and facilitates the construction of two additional nuclear power plants to help reduce coal consumption. The buildings sector is relatively energy-efficient, also by employing large district heating systems, 75% of which are delivered by fuel-efficient CHP plants. Finland has the largest share of biofuels in total primary energy supply among all IEA countries (IEA, 2013b).

Norway generates almost all of its electricity from abundant and affordable hydropower, which is well integrated into the Scandinavian grid. The use of hydroelectricity as the main energy carrier since the 1970s sets Norway apart from its neighbors and other countries (IEA, 2011). The building sector is increasingly energy-efficient, and mainly runs on this hydroelectricity. Norway's power-intensive metallurgic industry has improved its carbon productivity substantially since 2000. Even so, this is countered by the operations of its off-shore oil and gas industry – with many oil fields entering tail production which generates larger emissions per unit produced. The emissions from the domestic transport sector have also increased since 2000, but recently fallen due to rapid and widespread introduction of electric vehicles. The combination of domestic offshore and transport emissions growth since 2000 cancels out other energy efficiency measures (Statistics Norway, 2015), thereby thwarting Norway's ambitions for genuine green growth, making it a laggard compared with EU28 or OECD groups (Figures 1 and 2).

3.4 The Nordics' performance in a global perspective

The performance of the Nordics (as shown in Figures 1 and 2) demonstrates that the required decarbonization rates are empirically possible for longer periods at national levels (Sweden, Denmark, Finland) with different industry structures, irrespective of their various different starting points. Yet, as green growth critics have pointed out, it remains true that – in comparison to Sweden, Denmark and Finland – the largest emitting countries and groups, such as the US, China, India, the EU28 and the OECD, have not achieved this level of carbon productivity over the same time period, see Figure 3.

[Figure-3]

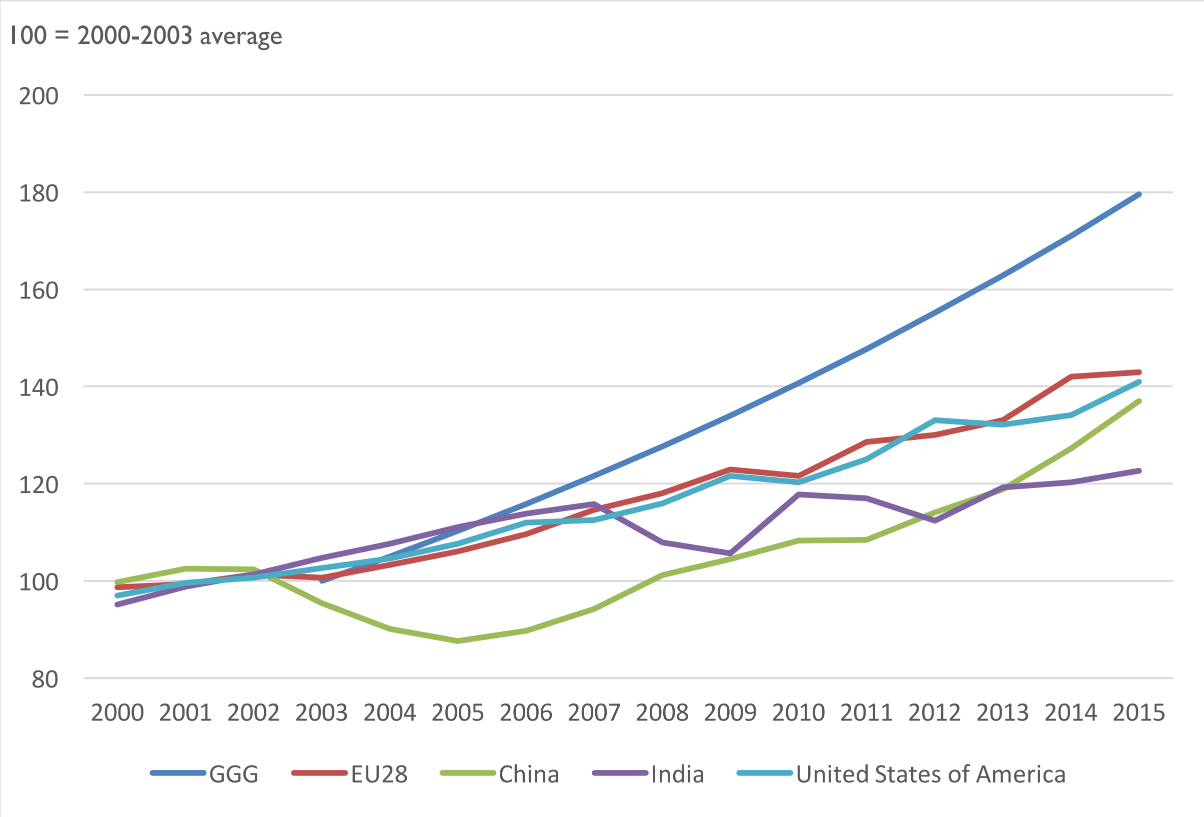

Figure 3: Genuine green growth relative to the development in world's most populous states 2000-2015. Baseline 100=average 2000-2003. GGG=5% carbon productivity pa from 2003. Sources: UN: GDP from United Nations Statistics Division, CO2 from UNFCCC, CDIAC and BP, via GlobalCarbonAtlas.

Figure 3 shows that for the largest economies in the world, the development is far from genuine green growth over the entire period. Yet, it is rather remarkable that since 2011, as can be seen from the curve, China has achieved average levels of 5.1% pa (2012-2014). Back in 2002-2003, China had a *negative* green growth at -10% pa, i.e. "dirty growth." If the numbers can be trusted, and if China can keep up this new record rate in the coming years and decades, we may also witness a first turnaround when it comes to genuine green growth in a major economy. China's new 13th five-year plan for 2016-2021 (March 2016) sets a carbon intensity target that is 50% below 2005 levels by 2020. It also has a new 65% carbon intensity reduction target by 2030. This means an annual carbon productivity rate of CAPRO>4% pa until 2030. Many are now expecting China to over-achieve on these targets (Green and Stern, 2016; Ng et al., 2016).

The primary focus of this paper is the research question: "What is 'genuine green growth' – and can it be found in the Nordics?" This section has established that "genuine green growth" - as defined and operationalized by an CAPRO >5% over an extended period of time - can indeed be found among a majority of Nordic countries since 2000.

4 – Discussion of fairness, scoping and rebound issues

4.1 The dynamic fairness of the CAPRO indicator

Applying the carbon productivity criterion of CAPRO >5% to all countries potentially addresses the imbalances in future climate emission responsibilities between the richer and the poorer countries in a dynamic way. From Table 1 and section 2.3 above, it became clear that the global *average* carbon productivity needs to improve by at least 5%. This enabled us to move beyond the original definition of green growth (1) $\Delta RP > \Delta GDP$, since this definition does not give any criteria for what is sufficient, and thus is weak. A stronger, sufficient version of green growth definition must take into account the science-based findings that ΔRP must at least be >5% pa.

The definition of genuine green growth in (3) CAPRO >5% can give poorer countries ample room for rapid economic growth, while rich countries – with empirically slower growth rates, and which have reached a high degree of saturation in terms of expansive economic growth, and are projected to grow at a slow rate until 2050 (at or below 3 % pa) – must achieve larger absolute emission reductions to achieve the same rate of change. The genuine green growth definition – maybe paradoxically – allows for some countries with a very high economic growth rate to increase absolute emissions during their catching-up period. Thus, if India grows its economy by 7% as measured by GDP (double the global average of GWP), and it has a CAPRO of 6%, it follows that its emissions go up by ~1%. But since (1) is not fulfilled this would be gray growth, not green. However, since this CAPRO is higher than the global average, and higher than 5% (which is needed for the pathway to 2050 for <2^{o}C target), it still contributes to lifting global *average* carbon productivity. We then have a situation where it cannot be defined as green growth by the weak definition (1), i.e., attaining absolute cumulative reductions in GHG emissions within the climate planetary boundary, but qualifies by the strong definition (3), a measureable pace of carbon productivity improvement > 5 % pa.

As countries get richer (as measured by GDP/capita) their average GDP growth rates universally decline, as developed countries have lower rates (Gordon, 2016; Pritchett and Summers, 2014; Randers, 2016). Thus, a developed country with a GDP growth rate of 1-3% pa would also need to reduce its absolute emissions by at least 2-4% pa for its CAPRO to be >5%. Not least due to the higher historic emissions per capita of richer countries, this could be argued to be fair. The same requirement of CAPRO>5% for genuine green growth also allows for poorer countries to "catch up." High GDP growth rates tend to be associated with developing countries more than developed countries. Their carbon emissions can increase if needed to fight poverty by growing their GDP >5% pa. As long as CAPRO>5% we would argue that this should be regarded as genuine green growth (since it improves the global average sufficiently per unit of value added).

Consequently, the dynamics of the indicator contribute to a fair development in the sense of giving room for poorer economies (low GDP/capita) to grow their economy rapidly – even if somewhat increasing the carbon emissions – for a while. As these countries grow richer, their growth rates will fall over time and the absolute GHG reductions kick in. The same simple definition (3) applies to all.

At sub-national level the same applies: Any city, county or state that can grow its value added strongly, while maintaining ΔRP >5%, will contribute to moving the country average and the global average in the right direction. Any companies with a rapid economic growth that also deliver CAPRO>5% pa will then contribute to out-competing and crowding-out companies with weaker green growth. The underlying idea is that stimulating widespread, rapid, genuine green growth can contribute to out-competing gray growth companies through market dynamics. The development in the US domestic power sector, where gas, wind and solar-power plants have been replacing and out-competing conventional coal-based utilities, can help illustrate that.

Given the likelihood that average GWP will be around 3% and declining over time, a CAPRO >5% will result in a >2% reduction in climate emissions pa, which is consistent with the science-based targets of <2°C. If nations aim for the more ambitious 1.5°C target, then the same principle can be applied, but CAPRO requirements move even further up, to >7% or even >9% pa in the coming decades (Jackson, 2011; Rockström et al., 2017). The allocation of future responsibilities can in any case be said to be fair and dynamic because they are now tied directly to each unit of future economic output, without restricting those (poorer) countries with a need to catch-up. As richer countries in the long term see a trend of GDP decline towards zero, they can still maintain a CAPRO >5%, for instance by replacing fossil fuels with renewables. Such futures opens for a possibility of economic a-growth (van den Bergh and Kallis, 2012), a situation where there is economic development even if growth in the GDP metric is no longer of significant importance to the well-being of their citizens.

4.2 The scope of carbon productivity: Territorial emissions or consumption - scopes 1, 2 or 3?

Critics of green growth are eager to point out that leading countries (such as Sweden or Denmark) mostly achieve a higher carbon productivity by outsourcing their dirty production to emerging economies where environmental standards are lower (Jenkins, 2012; Peters et al., 2011; Weidman et al., 2015). This counter argument seemingly invalidates the achievements of green growth by including the carbon footprint of the imports to the country's domestic consumption.

This issue regards scoping: Who are responsible for improving carbon productivity across the entire value chain and life cycle of products (Haslam et al., 2014)? The two main answers are: First, all entities are (should be) responsible for the emissions occurring within their own territory/operations and securing ΔRP>5% there. If this is gradually applied globally, it will eventually secure the overall performance of the world economy.

Second, any attempt to include emissions from elsewhere will result in double accounting of carbon emissions (unless complex accounting and negotiation precautions are taken): If one includes emissions embedded in imported consumption, emissions will be accounted for both in importing and exporting countries. All countries would then be incentivized – in their reporting of carbon productivity – to maximize the positive effects from the use of their exported products abroad, and to minimize the negative impacts of imports. However, reporting authorities have little or no direct control over either numbers. The most consistent practical way out of this conundrum is to strictly stick with domestic production emissions, and then work to bring more and more entities across world trade into the ΔRP>5% requirements. This could then gradually be expanded to cover the entire life cycle of all products traded, e.g. by requiring this performance level from any supplier to public or private procurement with cascading effects. Another approach is for nations to join in 'climate clubs' by applying a common, substantial carbon border tax on the trade of resource-intensive goods (Nordhaus, 2015).

It should be recognized though that full input-output accounting of all GHG emissions in a nation or along a value chain in business, including both import and export, can still be an important as a tool for behavioral change among citizens.

4.3 Carbon productivity killed by the rebound effect?

A third counter argument frequently encountered against resource productivity as a main sustainability solution is the rebound effect (Santarius, 2012; Saunders, 2000). The literature on this is large, but the empirical findings – particularly on macroeconomic rebound – are inconclusive (Santarius et al., 2016; Sorrell, 2009). In general, this counter argument says that any emission reductions and costs saved by better resource productivity will be offset by an increased volume of production and consumption. There are both direct and indirect rebounds: Thus, if a car uses 10% less gas/mile, owners may be tempted to drive 10% or more, rather than saving the gains (direct). Or a homeowner who cuts energy bills by better insulation may be tempted to purchase an extra airplane ticket from the savings (indirect).

The first pro-argument is that the first definition (1) ΔRP>ΔGDP, avoids this pitfall at a national level by claiming that resource productivity must at least be higher than the national consumption growth rate (GDP). When applied to the national economy as a whole, this rules out excessive rebound effects from the start by definition, as that makes for gray growth. The second pro-argument is that all sectors and industries must – in genuine green growth – perform at ΔRP>5% pa. Thus, even the aviation companies, utility companies and oil companies must all improve their CAPRO at least at that rate, irrespective of consumer behavior and market growth rates. The third pro-argument is that – at least in richer countries – the overall consumption and production (GDP) exhibits a declining long-term trend down to 1-3% pa, despite all attempts by politicians and other key players to force growth higher (Gordon, 2016; Randers, 2016). Then, if the country improves its CAPRO >5%, this means that its absolute emissions will yearly fall by >2%, effectively countering the economy-wide rebound effect, in spite of possible shifts in consumption behavior (such as a shift from utility costs to more transportation). For this to happen all sectors, including aviation companies, must be held accountable for CAPRO >5% pa.

5. Conclusions and Policy Discussion

The paper has proposed definitions to distinguish between three models of economic growth for the 21st century: Gray growth, green growth and genuine green growth. Gray growth has been defined as ΔRP <ΔGDP. Green growth is ΔRP >ΔGDP, while genuine green growth is ΔRP >X% where X expresses the requirement for minimum annual productivity improvements relative to a target for the planetary boundaries within a certain time frame. For the climate boundary, the peer-reviewed studies reviewed converged on a value of CAPRO >5% pa until 2050. We do recognize that CAPRO requirements may change as climate science advances, as well as with deviations in future GDP growth.

From reviewing the main Nordic countries, we found that Sweden, Finland and Denmark have delivered genuine green growth with CAPRO at 5.7%, 5.5% and 5.0% pa respectively over a reasonably long time period (2003-2014). Norway has seen gray growth in the period, and is not doing its fair share.

There are limitations to the use of carbon productivity rate, CAPRO, with regards to the fairness, scoping and rebound issues. And, for planetary boundaries other than climate, complementing CAPRO with broader resource productivity indicators will be needed. Yet, for green growth- and energy-policy, to start with expressing the economy's overall resource productivity through CAPRO offers several advantages in its simplicity and particularly for communication with the public and politicians. The same requirement of CAPRO >5% in rate of annual change can be applied to indicate whether countries, sectors, states and cities are achieving genuine green growth in relation to the 2^{o}C target, and thus doing their fair share.

To engage a broader public in a green growth narrative requires a consistent linguistic framing of the issue as a gain and "up"-issue, not as a loss, reduction, decrease, cost, cut and "down"-issue. According to cognitive-linguistic studies (Lakoff and Johnson, 2003; Stoknes, 2015) there are well-documented psychological reasons to prefer using carbon productivity over intensity indicators, since carbon intensity discourse relies on "down"-framings, while carbon productivity frames the issue as a way of going "up". It is an approach that highlights the need for climate communications to focus on doing more good, and not just less bad (McDonough, 2013). The same arguments applies to preferring "green growth" over "degrowth" (Drews and Antal, 2016). Hence, we would recommend to replace the use of carbon intensity indicators with carbon productivity improvements per year when informing the public discourse. Rather than setting an economic goal for GDP, one can shift the goal towards genuine green growth, measured in CAPRO. As illustrated in figures 1, 2 and 3, these graphs visually point "up", both metaphorically and subliminally hinting at progress to good lives and a brighter win-win future. This holds the psychological potential for activating emotionally powerful neural networks, underlying public engagement (Weber and Johnson, 2012; Westen, 2008).

It is clearly demanding for most countries to deliver genuine green growth at the required sustained rates of CAPRO >5%. But that is the minimum level towards 2050 if the world is to achieve the Paris Agreement without large scale negative emissions after 2050. For more ambitious targets like 1.5^{o}C, even higher rates like CAPRO >7% might be needed, but the indicator and the principle of science based targets, remains the same.

Critics of green growth are wrong however in claiming that there is no evidence for genuine green growth happening since 2000. External factors such as high annual variability from business cycles, abrupt shifts in trade, warmer winters, exchange rates and financial crises may either thwart – or boost – the results from policy interventions of delivering on carbon productivity in a year-to-year perspective. But over the longer term the pattern becomes clear, as with the Nordic countries. If politicians, corporations and voters continue to prioritize economic growth, then reframing that to genuine green economic growth – like Sweden, Denmark and Finland, and recently China - may be the only way forward that climate stability will allow for (Jänicke, 2012). Anything less will, according to current climate science, continue to overshoot the planetary boundaries and thus undermine the very human wellbeing that economic growth attempts to promote.

Genuine green growth at CAPRO > 5% probably becomes, then, the only model that economic development can take, if the world is to stand a reasonable chance of attaining the Sustainable Development Goals (of equitable and sustainable economic development for all) within planetary boundaries. But if global average GDP – against current trends and expectations – becomes higher than 3%, the CAPRO requirement would have to be adjusted upwards. The same would be needed if a 1.5^{o}C target is adopted. Our recommendation is therefore that in addition to having genuine green growth as an economic strategy that countries ideally set absolute emission pathways as a legal guarantee, for instance by adopting the global "carbon law" of halving emissions every decade into national law (Rockström et al., 2017). Sweden has done this in its 2017 climate law. Furthermore, to stay within all nine planetary boundaries, carbon productivity indicators also need to be complemented with resource productivity indicators of other material flows, ecological footprint, biodiversity, etc.

This article has demonstrated that genuine green growth is empirically possible when measured as carbon productivity rates higher than the consensus value of 5%. Further, it can be empirically found at high, sustained levels among several Nordic countries, and in China in recent years. It has not discussed the barriers as to whether these leading examples can be rapidly universalized to achieve overall, global genuine green growth. Likewise, more research is needed to see if resource productivity along the lines of the tentative definition (4) ΔRP >5% is sufficient for other planetary boundaries than climate.

Despite the challenges for modern economies to achieve genuine green growth, the default alternative remains the gray growth model. But continuing with gray growth is – to use a dramatic but possibly appropriate metaphor – suicidal. While genuine green growth may be a highly unlikely for large and culturally diverse nation states, we would nevertheless propose this as a normative goal for consideration by any economic entity. By comparison, working for genuine green growth is rational, and even in countries' own rational self-interest (Green, 2015). When it comes to the possibility of continued economic growth, the slogan seems true: Grow (at CAPRO >5%) or die!

Appendix 1 of 1: Carbon productivity data at national and corporate level

Table 1appears inside the article. Tables 2-3 are best put in appendix.

Table 2: Carbon Productivity from OECD Stat: Production-based CO_2 productivity in real GDP per unit of energy-related CO_2 emissions in US dollars (2010) per kilogram, Source OECD-Stat.

Numbers in USD 2010/kgCO_2 These are the raw-data used for generating figure 1.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Sweden	6,12	6,31	6,25	6,25	6,73	7,37	8,13	8,71	9,07	9,08	8,51	9,48	10,19	10,82	11,13
Finland	3,19	2,95	2,89	2,60	2,87	3,61	3,10	3,37	3,90	3,74	3,34	3,89	4,27	4,19	4,53
Denmark	4,27	4,17	4,22	3,83	4,37	4,78	4,27	4,70	4,95	4,87	4,90	5,56	6,33	6,03	6,99
8Norway	7,71	7,63	7,83	7,34	7,51	7,95	7,91	8,02	8,21	7,99	7,62	8,00	8,39	8,54	8,70
OECD-total	2,96	2,99	3,05	3,06	3,13	3,21	3,33	3,38	3,48	3,57	3,53	3,65	3,74	3,77	3,91

Table 3:
Carbon Productivity from UNstats and GlobalCarbonAtlas: real GDP divided by Total CO_2 emissions. Gross Domestic Product, measured in US dollars (USD 2005) at Nominal Exchange Rate (NER) for conversion to 2005 USD see: http://unstats.un.org/unsd/snaama/methodology.pdf CO_2 from GlobalCarbonAtlas, based on CDIAC, UNFCCC and BP.

Numbers in USD 2005/ kgCO_2. These are the raw-data used for generating figure 2 and 3.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EU28	2,91	2,92	2,98	2,96	3,03	3,12	3,22	3,37	3,48	3,61	3,57	3,77	3,80	3,91	4,21
OECD	2,40	2,44	2,47	2,48	2,53	2,60	2,69	2,73	2,81	2,90	2,87	2,96	3,06	3,08	3,19
Denmark	3,09	3,03	3,06	2,81	3,16	3,47	3,11	3,43	3,63	3,60	3,62	4,05	4,52	4,28	4,74
Finland	2,49	2,33	2,28	2,08	2,29	2,85	2,48	2,67	3,06	2,95	2,65	3,06	3,37	3,33	3,56
Norway	4,72	4,67	4,83	4,73	4,87	5,09	5,16	5,09	5,20	5,31	5,02	5,20	5,41	5,36	5,50
Sweden	4,78	4,76	4,79	4,85	5,13	5,55	5,79	6,12	6,33	6,46	6,12	6,80	7,27	7,45	7,78
China	1,19	1,26	1,30	1,17	1,10	1,12	1,14	1,23	1,30	1,30	1,33	1,33	1,40	1,46	1,55
India	2,04	2,10	2,14	2,21	2,27	2,37	2,43	2,49	2,33	2,30	2,56	2,56	2,45	2,49	2,46
USA	1,94	1,99	2,01	2,05	2,09	2,15	2,23	2,24	2,30	2,41	2,38	2,48	2,65	2,62	2,66

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