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Article

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European Journal of Economics and Economic Policies: Intervention (EJEEP)

Provided in Cooperation with:

Edward Elgar Publishing

Suggested Citation: Priewe, Jan (2022) : Growth in the ecological transition: green, zero or de-growth?, European Journal of Economics and Economic Policies: Intervention (EJEEP), ISSN 2052-7772, Edward Elgar Publishing, Cheltenham, Vol. 19, Iss. 1, pp. 19-40, <https://doi.org/10.4337/ejeep.2022.01.04>

This Version is available at:

<https://hdl.handle.net/10419/277533>

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Growth in the ecological transition: green, zero or de-growth?

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The article discusses the ongoing transition to climate neutrality in 2050 with a focus on the options of green growth, zero growth or de-growth. First, the stylised facts about the greenhouse effect and the status quo are shown with special attention to emerging economies as key contributors to greenhouse gas emissions since 1990. Globally, brown growth is still predominant. Since the Global South has to reduce emissions as much as the Global North, the resource-rich countries in the South face the gravest challenges. Second, different scenarios of the global transition with different combinations of GDP growth and reduction rates of the emission-to-GDP ratio are shown. The result is that both variables are important, but the reduction of the emissions ratio is more important than growth. Zero growth per se is not necessarily effective in reaching the Paris goals. Third, low green growth in the North is advised (under certain conditions also zero growth), and moderate green growth in the South. Zero growth without capital accumulation in a closed economy would terminate capitalism in its common definition, in contrast to zero growth in an open economy. Third, proposals from ecological economics for zero growth and de-growth are diverse and involve significant shortcomings, especially regarding the macroeconomic analysis.

Keywords: transition, growth theory, energy economics, decarbonisation, zero growth, de-growth, climate change, carbon prices, capitalism

JEL codes: O47, P18, P28, P47, Q01

1 THE ECONOMICS OF THE GREEN TRANSITION AND ZERO GROWTH

Reaching climate neutrality can be considered the most important global economic and ecological goal for the twenty-first century, with the decades until 2050 setting the course for the second half of the century. The governments of the signatory states of the Paris Declaration pledged in 2015 to the 2°C goal, if possible 1.5°C. The main streams of economists and policy-makers believe the climate issue is not related to GDP growth. Many reckon that the transformation as well as population growth in the global South will spur economic growth in tandem with innovations. In this paper, I argue that reducing the emission intensity (EI) of GDP – that is, greenhouse

* Email: jan.priewe@posteo.de. I am grateful for helpful comments from the reviewers and from participants at the De-growth, Zero Growth, and/or Green Growth workshop, 22–23 September 2021, and at the Macroeconomics of Social–Ecological Transition conference, 28–30 October 2021.

Received 14 October 2021, accepted 17 January 2022

gases (GHG) per unit of GDP – to a level commensurate with the Paris goal cannot be isolated from the GDP growth trend. Since decarbonisation can be reached, in principle, by a reduction of the EI or by a reduction of output growth, the mix implies a trade-off.¹ The reduction rate of the EI (i in the following, with positive sign) has to exceed approximately the GDP growth rate g in order to shrink GHG emissions (de-growth rate e). Globally, the world domestic product (WDP) followed a growth trend in the period 1990–2018 higher than i , resulting in GHG emissions rising by 1.5 per cent p.a. and CO₂ by 1.7 per cent p.a. Such performances of emissions in general are called ‘brown growth’, whereas ‘black growth’ would occur if the EI would grow or remain constant. ‘Green growth’ would require the intensity to fall more than GDP rises so that emissions shrink, after peak GHG is reached (cf. Victor 2010 for this classification).² If GDP stalls or shrinks while the EI continues to drop, we have ‘green zero growth’ or ‘green degrowth’, respectively. Those who opt for unconditional high growth have to guarantee very high reduction rates in EI. This trade-off is more critical in the case of a limited time window, irreversible pollution (GHGs remain in the atmosphere predominantly for very long periods) and physically limited size of sinks for greenhouse gases. Hence, public policy has to gauge potential future reduction rates of emission intensity *and* GDP growth, including interactions of both and population growth; a deliberate reduction of future growth rates, potentially down to zero, cannot be excluded *ex ante* if the Paris goals are not postponed. Whether temporary de-growth is necessary has to be investigated too.

In the following, GDP is used in the standard National Accounting manner, despite shortcomings. If slow or zero growth occur, it is assumed here to be not due to market-driven factors (waning technical progress, demography, satiated consumption, fading animal spirits, etc.), but to the need to curb growth in order to meet climate policy goals which likely poses a conflict of interests among entrepreneurs and governments.

I discuss brown, green, zero and de-growth in the context of the global decarbonisation transition. In Section 2 the stylised facts about the transition are exhibited. Then eight scenarios with differing growth rates and EI rates are compared (Section 3). Core theories of ecological economics are consulted in order to identify theoretical guidelines and reject misguidance (Section 4). Section 5 concludes.

2 STYLISED FACTS ABOUT THE TRANSITION TO ENVIRONMENTAL SUSTAINABILITY

Coping with climate change is the key issue in the general environmental transition because climate change impacts several other ecological and social problems: land use,

1. This notion is based on the well-known IPAT formula: $I = PAT$. The environmental impact I results from the product of population (P), affluence (A) and technology (T) (Ehrlich/Holdren 1972).

2. To be precise, the borderline between brown and green growth is defined by constant emissions: if g is given and n the number of years analysed, the reduction rate of emissions i' which leaves emissions constant over the period is $i' = -\left[\left(\frac{1}{(1+g)^n}\right)^{\frac{1}{n}} - 1\right]$. If $g > i'$ it is brown growth; if $g < i'$ it is green growth. Some authors use the terms relative and absolute decoupling of pollution/emissions and GDP growth. The former exists if the change rate of emissions e is less than growth of GDP g (and $g > 0$), while the latter adds to these conditions $e < 0$. Green growth in Victor's definition, which is used in this essay, means absolute decoupling with $e < 0$ and $g > 0$.

scarcity of ecological sinks, lack of arable land and nutrition, water scarcity and food production, the diversity of species, and, last but not least, the well-being of future generations of mankind. In the Paris Agreement the signatory states pledged to the goal of limiting global warming to ‘well below 2°C’ above the pre-industrial temperature and to strive for reaching the 1.5°C target by 2050. The declaration refers to all GHG emissions, which should be lowered to a level that is in balance with the natural sinks, hence not necessarily zero. Peak GHG should be achieved as soon as possible. Developed countries should take a leading position and support developing countries. Not mentioned is the term ‘climate neutrality’. Since 2015, debate has focused on the eradication of CO₂ emissions until 2050 and climate neutrality, a term open to many interpretations, while methane reductions have been less highlighted. Climate neutrality is often conceived as including ‘negative emissions’ of GHG to be allowed to some extent, especially after 2050 (cf. Fuss et al. 2018).

2.1 The global residual carbon budget

The Intergovernmental Panel on Climate Change (IPCC) has developed the residual carbon budget approach regarding CO₂ emissions. This approach aims to achieve the goals of the Paris Agreement. Following the 2021 interim report (IPCC 2021), the residual budget for further global CO₂ emissions in a scenario for reaching the 1.5°C goal with a 67 per cent probability has a size of 400 gigatons (Gt) CO₂, and 1150 Gt to achieve the 2°C goal by 2050. If the present global CO₂ emissions are estimated at close to 40 Gt p.a.,³ the 1.5°C CO₂ budget would be used up in ten years and the 2°C budget in 29 years. Global warming by +2°C cannot exclude that crucial tipping points for the world climate might be triggered. The IPCC uses complementary goals reduction scenarios for methane and the other gases. Methane emissions should be halved by 2050 according to the IPCC in the most ambitious scenario (IPCC 2021: 17, scenario 1-1.9). The residual budget approach takes into account that a large part of GHG emissions is absorbed by sinks (oceans, forests, ice and permafrost in areas at or close to the Arctic and Antarctica). Due to the fact that the lifetime of CO₂ is almost infinite and of other gases also long (apart from methane with an average of nine years), GHG emissions cumulate in the atmosphere. If so-called negative emissions after 2050 are to be avoided, climate neutrality means that almost all GHG emissions have to be stopped. Technologies or policies for negative emissions such as carbon capture and storage (CCS) or geo-engineering are considered critical by most climate experts (for example, Schandl et al. 2016; Pfluger et al. 2017 calling for 95 per cent CO₂ reduction; Holz et al. 2018; Edenhofer/Jakob 2019: 64; UBA 2019: 6; SRU 2020: 62f). Also, afforestation and reforestation have limited effectiveness and might at best allow a respite for a few years (cf. Bastin 2019; Bastin et al. 2019; Veldman et al. 2019). Debates are ongoing.

3. The statistical source for all GHG emissions used by the IPCC is Climate Watch (CAIT) from the World Resources Institute. The latest data for global CO₂ emissions are from 2018 with 36 442 megatons (Mt), excluding emissions due to land use and changes in land use and forestry (LULUCF). I assume CO₂ emissions in 2020 at around 40 Gt. CO₂ accounts for almost three-quarters of all GHG emissions if other gases are counted as CO₂ equivalents (CO₂e). Methane (CH₄) accounts for 16.9 per cent of GHG, nitrous oxide (N₂O) for 6.3 per cent, and F-gases for 2.3 per cent; net LULUCF is estimated at 2.8 per cent (data for 2018 from CAIT retrieved on 7 October 2021).

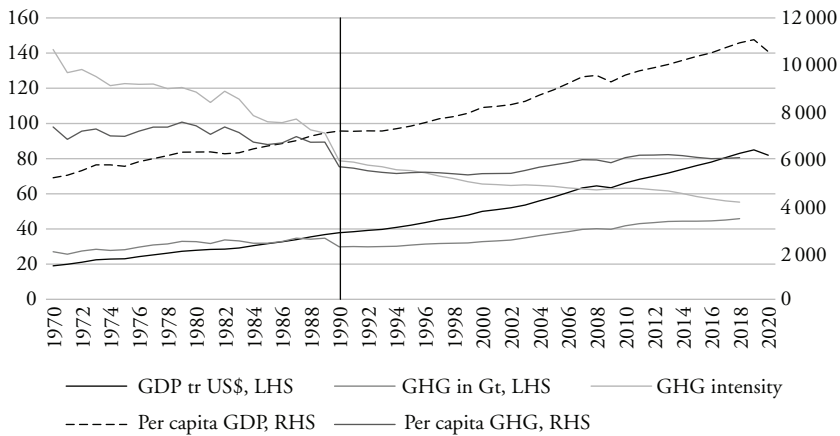
2.2 GHG and GDP dynamics

In the period 1990–2018 global GDP (in constant 2010 US\$)⁴ grew by 2.8 per cent p.a. while the world population grew at a rate of 1.3 per cent so that GDP per capita rose by 1.5 per cent p.a., as fast as GHG emissions (data in this section from WB 2021 and OWID 2022). Light relative decoupling of GDP and GHG did occur, but no absolute decoupling (Figure 1). The average growth rate of CO₂ emissions (including LULUCF) is 1.7 per cent in this period. GHG emissions have not yet reached a peak (except for the small dent in 2020 due to the COVID-19 crisis, actual data for 2020 still missing). Almost half of GDP growth was driven by population growth when assuming that per-capita growth is independent from population growth. Of course, the interaction of both growth rates is complex. The GHG intensity shrank by 1.3 per cent p.a., hence it was brown growth. If the global GDP were to drop by 50 per cent from the level of 2018 down to the level of 1994, annual GHG emissions would still be 23 Gt if the improved emission intensity of 2018 were applied – this is a bit more than halving global emissions of 47.5 Gt in 2018, but far too little to reach the 1.5°C or 2°C goal. With zero per-capita growth 1990–2018, GHG would have remained constant at the 1990 level, and with global zero growth of GDP and the same reduction of GHG intensity as *de facto* occurred, GHG would have dropped by around 30 per cent in this period, all else unchanged. The increase of GHG emissions 1990–2018 by 54 per cent compared to a scenario with zero per-capita growth was entirely due to GDP growth above this line. Had there been no GHG intensity improvements since 1990 and were GDP growth unchanged, GHG emissions would have been 41 per cent above their actual 2018 level. In other words, without speeding up the reduction of GHG intensity by new technologies and/or changed behaviour of consumers, even heavy de-growth or zero growth of GDP cannot do the job. The need for speed in climate policy echoes the speed of the build-up of pollution in the atmosphere. Cumulated GHG emissions grew by not less than 13.6 per cent p.a. from 1990 until 2018.

The relationship between GDP per capita and GHG (CO₂) per capita shows great variance across countries. At the global level in 2018, GDP per capita was – in constant 2010 US\$ – 10 935 p.a. (amounting to current US\$11 345) while average GHG was 6.0 t (CO₂ 4.8) per capita. Comparing countries with similar CO₂ load or with similar income levels shows great disparities: the US emitted in 2018 15.2 t CO₂ per capita with a GDP per capita of current US\$63 064, while Germany with 24 per cent lower income per capita caused 43 per cent less CO₂ emissions (8.6 t per capita). These figures disregard trade-related imported CO₂ consumption (see below). Even more telling is the comparison between Poland and Germany: both countries emitted almost the same amount of production-based CO₂ (Germany 8.5 t and Poland 8.3 t), but Germany's GDP per capita was 2.8 times higher (2018). China's production-based CO₂ intensity was five times higher than Germany's, although Germany has a mediocre rank compared to Sweden or Switzerland.⁵ Obviously, there are enormous differences in CO₂ intensity, both

4. Data using constant purchasing-power parity (PPP) US\$ show higher growth rates for developing and emerging economies. PPP data rely on several assumptions, including a constant ratio of PPP-based GDP to GDP in constant US\$ over the period 1990–2020. Therefore, I use GDP data in 2010 constant US\$. Country-specific growth rates of GDP do not differ in either metric but global GDP growth is higher in PPP terms.

5. Strong differences between countries of the same income group can be caused by carbon intensity of GDP due to different technologies, (non)usage of nuclear power, carbon-intensive trade imbalances, production structure and different natural endowments (for example, water resources), so that comparisons must be made with caution.



Notes: GDP in constant 2010 US\$. Until 1990, data for GHG were based on a different methodology, causing a break in 1990 (indicated by the vertical line). GHG counted in CO₂ equivalents. GHG data since 1990 differ slightly from Climate Watch data (CAIT 2022, 3 January 2020). Definition of total GHG in WB (2021).

Sources: GDP, GHG and population data from WB (2021), CO₂ data from OWID (2022). GHG intensity is GHG/GDP (scaled up by 100). Own calculations.

Figure 1 Global GDP and GHG emissions (in Gt and kg per capita), 1970–2020

amongst rich countries and amongst richer and poorer countries. The key point here is that most countries in the Global South use – imported or domestic – fossil energy (often coal) as their primary energy source and for electricity generation, and many but not all rich countries still do the same. On the global scale, fossil energy made up 84.3 per cent of primary energy consumption and 63.3 per cent in electricity generation (2019).

2.3 Regional distribution of emissions

How about the regional distribution of GHG between the Global North (here defined as high-income countries in the World Bank classification) and the Global South (low- and middle-income countries)? GHG and CO₂ data usually follow statistics based on the geographic origin of production, which excludes trade with GHG- or CO₂-intensive goods and services. First, we look at production-based (PB) data, then we compare them with consumption-based (CB) data regarding CO₂. A long debate about carbon leakages and the so-called environmental Kuznets-curve has preceded recent more systematic findings. The notion of a general increase of emissions in the course of increasing income per capita and decreasing emissions beyond a certain income level could not be confirmed. There is no general pattern (cf. Peters et al. 2012 and Mir/Storm 2016 for overviews).

In 2018, one-third of global GHG emissions came from production in the Global North, two-thirds from the Global South (with China emitting 26 per cent of global emissions) (all data in this section from WDI 2021). The increase in global GHG emissions in the period 1990–2018 was 54 per cent, but only 4.2 per cent in the North and 99 per cent in the South; 57 per cent of the global increase originated in China, and 27.6 per cent in lower middle-income countries (to which India contributed the half). There is no doubt that

carbon-based industrialisation of the South and neglected reduction from high per-capita levels in the North are the twin parts of the pincers that heckle the climate: dynamic forces on the one side and lethargic former giants on the other act together. If the latter were able to reduce all GHG emissions down to zero by tomorrow, with technology and/or massive de-growth, and the South were to U-turn to zero growth with constant emissions of 31 Gt p.a., the residual budget would still be used up rapidly and a 3°C path to doomsday would still be looming. 62 per cent of global GHG emissions in the year 2020 would remain.

From a historical perspective, 25 per cent of total cumulated PB CO₂ emissions in the period 1750–2020 took place before 1970, most likely predominantly in countries of the Global North. Until the year 1900, it was only 5.5 per cent. 54 per cent of cumulated CO₂ emissions emerged after 1990, 65 per cent after 1980 (data from OWID 2022; similar data from Wackernagel/Beyers 2019: 6). Regarding countries/regions and cumulated PB CO₂ emissions (1750–2019), the largest emitters are North America with 29 per cent of global emissions, the EU-28 with 22 per cent, China with 12.7 per cent, the Russian Federation with 6 per cent, Japan with 4 per cent and India with 3 per cent – altogether 76.7 per cent of global emissions in this period. Yet the dynamics after 1990 come from the Global South.

CB CO₂-emissions, which include CO₂ incorporated in exports and imports, show net imports of advanced economies and conversely net exports of emerging and developing countries (country-specific data since 1990 from OWID 2021). For the large emitters, we summarise (for 2019) excess CB emissions over/under PB emissions: the US +7 per cent, Germany +15.9 per cent, the EU-28 +21.0 per cent, Japan +16.5 per cent, France +33.6 per cent, Sweden +66.0 per cent, the UK +41.1 per cent, and Latin America +6.5 per cent; whereas large net exporters of emissions are: Africa –37.0 per cent, Kazakhstan –22.7 per cent, Russia –14.7 per cent, China –10.0 per cent and India –8.2 per cent. In many countries the CB emission trends perform in tandem with PB emissions but at different levels. A number of countries exhibit downward-trending emissions of both types, such as the US (since 2007), Germany since 1990 (no earlier data available), Sweden, Denmark and Switzerland. Data for CB GHG emissions are not available.

The general proposition that the dynamics in CO₂ emissions stem from East Asia and other emerging economies is not falsified if CB data are used. However, Africa and a few other resource-rich countries – lower middle- or low-income countries – play an additional strong role as suppliers of fossil energy to advanced countries as well as to emerging economies.

Summarising these facts about the climate crisis makes clear that the problem is not due to exhausted fossil resources; by contrast, there are still abundant fossil resources in the ground, which must not be used and need to be preserved as a common good for the planet, with no pecuniary value any longer. This is likened to an expropriation of the owners.⁶ The true resource constraint is the limited capacity of natural sinks for the absorption of GHG. Warming of the atmosphere is a result of the emergence, perpetuation and scaling-up of extractive capitalism since the pioneer industrialisation of Europe, based on exploitation of nature and labour, replicated by emerging economies since around 1980 and reinforced by high per-capita emissions in advanced countries. GDP growth alone cannot explain the crisis; technology and structural change with excessive pollution intensity are involved as well, accompanied by the competition of nations rather than their cooperation.

6. Edenhofer/Jakob (2019: 74) report that the global fossil energies under the ground are estimated at 15 000 Gt CO₂.

For most countries on the globe, brown growth regarding GHG emissions still predominates until peak GHG. In a number of countries, brown growth has mutated into green growth with relative decoupling of output and emissions. Hoped-for absolute decoupling is just another phrase for achieving decarbonisation.

Regarding the severity of the problems to be solved in order to stop overheating the planet by 2050 or the end of the century, the brunt of the burden has to be shouldered by the Global South, especially those countries that have lived from brown growth. Countries such as Nigeria, Venezuela, Mozambique, Saudi Arabia, the Russian Federation and many others have to reinvent their fossil economies. They will suffer from the last phase of the resource curse and use all their financial wealth to build up new economies as if they were start-ups.

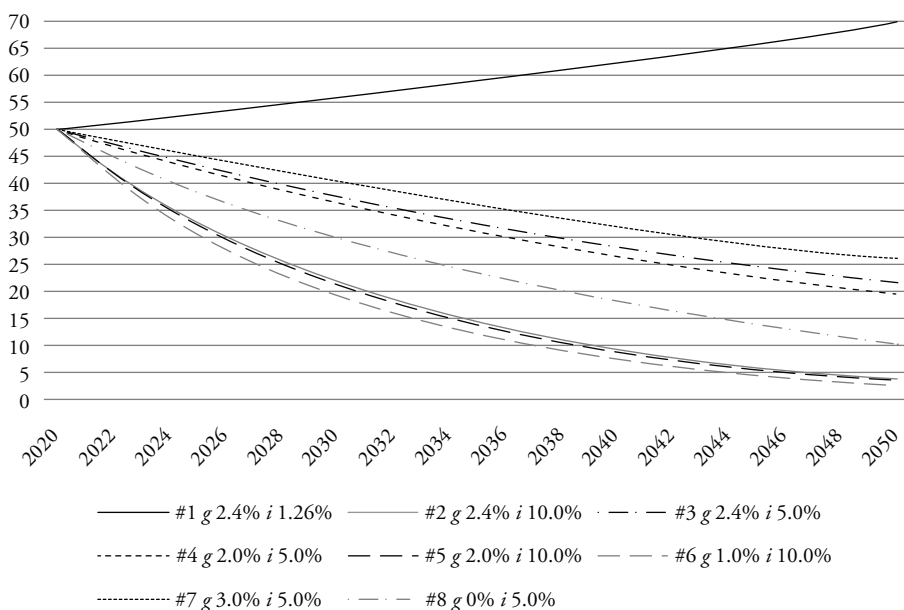
3 THE ECONOMICS OF GREEN TRANSITION

Green transition in this context means full decarbonisation and reduction of all GHG emissions down to a very low level, so that overshooting emissions and compensation with negative emissions can be minimised. The ‘net zero’ is then very close to zero CO₂ emissions in the year 2050, hence GHG emissions must not rise but be curtailed by close to 50 Gt or 1.66 Gt p.a. if a linear pathway is chosen (with a goal of –90 per cent, it requires 45 Gt and 1.5 Gt p.a.). At the beginning this implies a reduction of 3.3 per cent, rather than +1.5 per cent in the past trend (1990–2018). The quicker the reduction in the first years, the bigger the share of the residual budget for the following years. If this cannot be achieved, negative emissions of unknown size will emerge after 2050; they have to be captured with not-yet-existing technologies like ‘carbon dioxide removal’ (CDR) with CCS (CO₂ is separated in production processes and stored underground), direct air capture (DACCS), bio-energy capture (BECCS), geo-chemical CDR or by afforestation. Several scenarios from the IPCC include negative emissions after 2050. Many authors warn against CCS or recommend giving clear preference to curbing emissions.

3.1 Eight scenarios

The expected GDP and population growth in a status quo scenario has to be taken in account. The OECD expects a slight slowdown of world growth mainly in the Global South due to maturing emerging economies, toward a rate of 2.56 per cent p.a. 2020–2050 (OECD 2018). I assume a slightly more moderate growth rate of 2.4 per cent for the world, which could be 1.5 per cent for the North and 3.5 per cent for the South.⁷ Global population growth is forecast by UN DESA (2019) to be 0.74 per cent in the medium variant and 0.44 per cent in the low variant, rising to 9.7 billion and 8.4 billion in 2050, respectively, compared to 7.8 billion in 2020. This leads to a per-capita GDP growth of 2.78 per cent p.a. in the South and 1.34 per cent in the North. In sum, the global population will rise by one-quarter (medium forecast), and global GDP will more than double in this trajectory (+104 per cent), shown in Figure 2 as #1. Regarding GHG emissions, everything hinges on the speed of their reduction, if GDP growth follows the trend. I assume that GHG emissions in 2020 have reached

7. While the GDP of the Global North in 2020 was 63 per cent of the world GDP in constant 2010 US\$, it would be 48 per cent in 2050, given these assumptions.



Note: g is GDP growth rate; i is the absolute value of the reduction rate of GHG intensity; both p.a. Initial data for 2020 estimated by the author. The order of lines from top downward is: 1, 7, 3, 4, 8, 2, 5, 6.

Source: Author.

Figure 2 Eight scenarios: global GHG emissions in Gt, 2020–2050

around 50 Gt (after 48.9 Gt including LULUCF in 2018) as the starting point for all scenarios.

If the emission change rate is e and the change rate of the emission intensity is i and economic growth g , all per annum, we can conclude: $e \approx g - i$ and $i > g$ defined as green growth. As long as we exclude de-growth for GDP, the realistic range of g on a global scale lies between 3 per cent and perhaps close to zero, while the realistic range for emission intensity reduction has a range of 1.26 per cent (status quo) and perhaps > 5 per cent; the point is that the range of change for i is bigger than the range of change for g , if de-growth is excluded. If GHG emissions decline by around 90 per cent by 2050, it translates into an annual decline of 7.4 per cent. This is the i necessary in a zero-growth scenario. This implies that both rates do impact e , but since i exceeds g in all pathways while excluding de-growth, i has a stronger impact than g in emission reduction, which is demonstrated in Figure 2. Of course, interactions between g and i are excluded here, but are discussed below.

Scenario #1 in Figure 2 shows business as usual, with slightly reduced trend growth and GHG intensity falling, with the past-trend rate of 1.26 per cent p.a. This leads to GHG emissions of 64 Gt in 2050, 39 per cent more than in 2020. It is brown growth ($g > i$) and of course a no-go pathway leading to climate disaster. One bundle of trajectories with three scenarios delivers mediocre results (#3, #4 and #7), which approximately halve emissions by 2050 compared to 2020 and involve $i = 5$ per cent. The other bundle with three scenarios reaches the target (#2, #5, #6) assuming that some non-CO₂

emissions remain in the order of 3–5 Gt which corresponds to GHG reductions of around 90–94 per cent, respectively. All three have a very ambitious i of 10 per cent. In both bundles the difference of g in the range 1–2.4 per cent has little impact. The only zero growth pathway, #8, remains between the two bundles and does not deliver the 1.5°C goal, since i with 5 per cent remains too small. This demonstrates the trade-off: continuous de-growth (in GDP terms) would – statistically – be necessary if the intensity rate could not drop faster than 5 per cent, and with positive growth the intensity rate has to be > 5 per cent.

Now I use the necessary GHG reduction rate e^* as the policy variable (–90 per cent) and calculate different i rates under different growth assumptions. Status quo growth with 2.4 per cent requires i at 9.57 per cent; 2.0 per cent growth requires i at 9.21 per cent; 1.0 per cent growth requires i at 8.31 per cent; and zero growth requires i at 7.40 per cent.⁸ Hence, without ambitious reduction rates for GHG intensity, the 1.5°C goal cannot be accomplished, assuming that negative growth is unfeasible. Zero growth as the only or the key policy variable cannot reach the goal.

Table 1 shows the CO₂ reductions or increases in the same eight scenarios, compared to the Paris goals and the residual CO₂ budget of 400 Gt CO₂ for the 1.5°C goal and 1150 Gt CO₂ for the 2°C goal. The same scenarios as above reach the criteria for the 1.5°C trajectory (#2, #5 and #6). With a 2.4 per cent growth trend, a reduction of CO₂ intensity of not less than 10 per cent p.a. is necessary to achieve a reduction of 91.4 per cent of CO₂ (and also GHG in total) with minimal overshoot above the 400 Gt limit. Half a percentage point less growth yields only slightly better results in #5, whereas a 1 per cent growth pathway with a 10 per cent efficiency increase reaches 94.3 per cent reduction. Residual CO₂ and GHG remain in 2050 since the trend of intensity-reduction reaches zero asymptotically. The other scenarios are far off the goals, except that the 2°C budget is not yet used up in 2050 in all these trajectories, but #3 and 4 could

Table 1 Eight scenarios for GHG and CO₂ change, 2020–2050

Scenario	Residual 400 budget consumed	Cumulated CO ₂ 2020–2050, Gt	CO ₂ reduction 2020–2050, %	GHG change 2020–2050, %	1.5°C/ 2.0°C reached
#1 g 2.4 i 1.26	2029	1118	–7.8	39.3	No
#2 g 2.4 i 10.0	2041	440	–91.4	–91.4	Almost 1.5°C
#3 g 2.4 i 5.0	2031	792	–56.3	–56.3	2°C ?
#4 g 2.0 i 5.0	2031	754	–61.1	–61.1	2°C ?
#5 g 2.0 i 10.0	2043	425	–92.3	–92.3	Almost 1.5°C
#6 g 1.0 i 10.0	–	391	–94.3	–94.3	1.5°C
#7 g 3.0 i 5.0	2030	855	–47.9	–47.9	No
#8 g 0.0 i 5.0	2034	597	–78.5	–78.5	> 1.5°C

Note: g is GDP growth rate; i is change rate of CO₂ intensity of GDP assumed to be the same as for GHG.

Source: Author.

8. In another variant of zero growth I calculated a one-off output reduction by 5 per cent in 2030 leading to a reduced but constant level of GDP until 2050. This would require an average i rate of 7.24 per cent over the entire period rather than 7.4 per cent in flat zero growth – not much alleviation.

reach the 2°C goals only with strong leaps after 2050. That the rest of the GHG emissions, other than CO₂, still remain in 2050 is in line with the Paris goals.

A significantly different scenario has been presented by the International Energy Agency (IEA 2021). The starting point is the assumed world growth acceleration to 3.0 per cent p.a. (on average) until 2050, based on constant PPP US\$ which differ somewhat from constant US\$ used here. This growth leads to a 2.4-fold increase in global output in 2050. The IEA focuses only on CO₂ reduction with a target of a remaining volume of 7.6 Gt which amounts to an 80 per cent reduction if the same CO₂ base for 2020 were used as here. This implies a considerable CO₂ overshoot, captured with various new technologies which are not yet mature presently. This net zero target is in line with a 1.5°C pathway at only 50 per cent probability and therefore a higher residual CO₂ budget as used here. The implicit i is 8.0 per cent p.a. Hence higher growth leads to significant overshooting of emissions to be captured and contained.

The key question is how fast the pollution intensity can be changed. At first glance, i is a technology variable, yet behavioural and institutional changes also impact i , and most technology improvements require behavioural accommodation, like accepting masses of windmills in the neighbourhood, changing land-use regulations or accepting higher prices for renewable energy. i is also a measure of speed in modernisation, of how fast mostly well-known new technology can be spread worldwide and get implemented. i can be much better targeted than GDP growth: imagine targeting new and banning old technologies for cement and steel production, two heavily energy-intensive products, or imposing taxes or tradable permits on air flights. Controlling GDP growth to target GHG is like shooting birds with a shotgun. It is rather inefficient unless one believes that additional GDP brings *per se* more bad than good. Yet, as a general indicator for rebound and scale effects, it indicates the degree of pressure on using scarce natural resources of all sorts and it may be a better target than hundreds or thousands of targeted shots on excessive mass pollutants. Targeted climate policy measures may have an impact on GDP as well, so that raising i could dampen g . On the other hand, accelerating GDP growth – or maintaining high growth rates – in order to generate income and tax revenues to ease financing of delayed climate policy measures causes more harm than good.

3.2 Green growth in the transition?

Decarbonisation has to relinquish the old capital stock based on fossil energy (FE), which replaces or enlarges it by a new capital stock based on renewable energy (RE). The transition is a process of creative destruction, but the question is whether the change leads to growth acceleration, or is growth-neutral or causes decelerating growth. In the first case, green transition growth contributes to massive modernisation in all countries, especially if done at high speed in the first phase. But high speed also means high destruction of the fossil capital stock. The switch from FE to RE leads to an increase in electricity demand and a relative decrease in the demand for liquid or gaseous energies. So it is a global second phase of electrification, compared to the first wave which started in Europe and North America at the end of the nineteenth century. Traffic and heating/cooling of buildings will rely mainly on RE-based power generation, if more difficult 'Power to Liquid' (PtL) is excluded or delayed since technologies are not yet mature and most likely extremely dependent on mass-scale RE with a low energy return on energy investment (EROI). Broad-based electrification requires the redesign of many manufactured products, not only of cars. If the RE transition in power generation, in buildings (both construction and heating/cooling), in industry, in traffic and also in agriculture get momentum, a kind

of Kondratiev boom might emerge which could jeopardise the Paris goals via rebound effects and higher growth of the world economy. However, if new investments offset phasing-out of old capital stock, the net effect is close to zero. A recent study from the German think-tank Agora on the transformation of Germany by 2050 assumes, for instance, a growth trend of 1.3 per cent p.a., which is close to status quo projections (Agora 2021). Other studies confirm the growth-neutral character of the transition in the sense that pre-transition growth trends – with mild growth moderation – prevail, given no major policy change.

Another related pathway is the promotion of energy saving in all areas which would dampen the demand for electricity and synthetic fuels. While some authors expect a tripling of electricity demand around the globe (McKinsey & Co. 2020), others propose a broad array of energy-saving measures which supposedly could reduce energy demand by 40 per cent even with an increased quality of life (Grubler et al. 2018). Agora estimates an increase in electricity demand for Germany of 67 per cent by 2045 compared to 2021 (Agora 2021: 35), complemented by a considerable increase of hydrogen-based clean energy mostly imported from abroad.

If we assume that the emerging new energy system does not change the macroeconomic capital coefficient, then any growth rate of GDP involves a constant net investment, that is, a rising capital stock. The replacement of the old capital stock would change in substance, but not in quantity. Therefore, the transition could involve green growth due to a wave of broad-based reinvestments. It could be a reinvestment boom with accelerator and multiplier effects which peters out after several years. If the old capital stock were replaced prematurely, for example due to high carbon taxes or for other reasons, the capital coefficient would increase because the lifetime of fixed capital would be curtailed. This tends to raise the level of GDP, other variables unchanged. If avoiding high adaptation costs in the future due to severe climate change above 2°C is factored in, low or zero growth may be more in welfare terms than status quo growth rates. Furthermore, if low or zero growth generates pressure to improve welfare by redistribution and reallocation of resources – to build better and more preventive health care, avoid violent domestic and international conflicts, improve social cohesion and reduce criminality, and similar – less growth could be welfare-enhancing and save ‘defensive costs’. Avoiding fallacies by unrealistic assertions that less is more, better social accounting and new social consensus on more public goods and services as well as more equitable social standards are needed.

However, it is obvious that slowing economic growth in the transition period alleviates the task of reaching net-zero emissions in 2050. The roll-out of a new RE sector would have a smaller size than under a pathway with higher growth. While global GDP would double with 2.4 per cent growth in the period 2020–2050, it would rise only by one-third if GDP expanded by only 1.0 per cent. Lower growth and zero growth require reduced growth of private and/or public consumption; de-growth in GDP terms requires temporary absolute reductions before turning to zero growth. In all three cases the normal capital stock used for non-energy-related production would increase at a slower pace or shrink. Obviously, this is a bigger challenge for countries in the Global South with a much lower GDP per capita.⁹

9. GDP per capita in current US\$ (or in current PPP US\$) was nine times higher in the North than in the South (in PPP US\$ 4.7 times) in 2020 (WDI 2021). The threshold for classification for high-income countries is defined by the World Bank at US\$12 696 gross national income (GNI) per capita, with a conversion factor according the Atlas method which smoothes exchange-rate fluctuations.

From a purely ecological perspective a continuously shrinking economy in terms of GDP would ease the transition. Such trajectories seem tempting. Yet this view simplifies the issue at stake by disregarding everything else – as if the mammoth tasks of securing employment for a (by one quarter) larger world population as well as improving presently poor living standards for the majority of people could be managed easily with decarbonisation at the same time. Furthermore, the economics of zero growth and de-growth, understood as the prelude to zero growth, is uncharted territory. If the conventional understanding of capitalism is valid, a market system based on private ownership of the means of production, profit maximisation, capital accumulation and zero-growth in a closed economy would require a different economic system. In open economies, zero growth could preserve capital accumulation by net capital exports and corresponding current-account surpluses. This raises the notion of zero growth in rich countries and growth in the rest of the world. This is also a deep regime change.

So far, our scenarios have shown that those with low growth and high rates of emission reduction are more likely to reach the Paris goals. Even zero growth as such is only conducive to climate neutrality if coupled with emission reduction in the range of 7.4 per cent p.a. on a global scale. Since zero growth in the Global South is more than unlikely to be compatible with the sustainable development goals (SDG) enacted by the United Nations in 2015 for the following 15 years, zero or low growth might be a guideline only for the Global North, if de-growth is excluded.

To shed more light on the issues of zero growth and de-growth, I now consult ecological economics in a brief digression before I return to the transition issues.

4 ECOLOGICAL ECONOMICS AND THE DEBATE ON ECONOMIC GROWTH AND DE-GROWTH

Most classical economists believed that mature capitalism would stop growing, albeit for quite different reasons (cf. Priewe 2016). Malthus and Ricardo saw land as a constraining factor, but argued with different consequences; Smith believed in declining profit rates and falling capital accumulation and other not very clear reasons which led eventually to a ‘steady state’ in the sense of a stationary economy; Mill hinted at waning population growth and limitations of land and nature, falling profit rates, and the change of consumption patterns toward non-material activities. Marx believed in falling rates of profit in capitalism with diminishing capital accumulation which eventually leads to a new economic system; exploitation of nature was not seen as a constraint to economic growth even though the interdependence of nature and society was mentioned (‘metabolism’). Keynes envisioned, similarly to Mill, a fading appetite for profit accumulation and a rising demand for leisure instead of raising income and consumption, without any mention of natural constraints.

Neoclassical growth theory pushed land and other natural scarcities aside by assuming that technical progress can overcome the scarcity of nature. Natural resources including land were incorporated into the category of capital. The focus on unlimited factor substitution emerged, coupled with boundless technical progress and population growth; should the latter two factors wane, growth might run dry and morph into stationarity. Although negative externalities exist, they can be internalised and thus avoided by price-driven reallocation of factors – no reason to fuss. None of these theories, including microeconomic resource economics, is capable of explaining the role of nature for economic development or foreseeing impending disasters such as climate change with irreversible damage. None of the theories explains the embeddedness of the economy in the biosphere, which

subjects the economy to biophysical laws. I will now review in a very brief manner a few prominent authors from ecological economics, namely Kenneth Boulding, Nicholas Georgescu-Roegen and Herman Daly, and afterwards will discuss post-growth theorising.

4.1 Boulding, Georgescu-Roegen and Daly

Boulding (1966) called for a turnaround in seeing our economies as illimitable planes, as frontier economies or ‘cowboy economies’: ‘reckless, exploitative, romantic, and [with] violent behavior’ (ibid.: 7); instead, the planet should be considered as ‘spaceship earth’. The latter has no inputs from outside, apart from the sun, and no outputs to outside. The main sources of nature used for production are material, energy and information. For energy the second law of thermodynamics applies with rising entropy, but not so for materials which is seen in principle as recyclable with constant entropy. In an aside, he mentioned that pollution might be an even bigger problem for mankind than exhaustible resources, albeit no hint to the atmosphere was given. Throughput from the factors of production should be split in exhaustive, renewable and recyclable resources. Throughput could be measured roughly by the gross national product (GNP). The cowboy economy is geared to maximise consumption. ‘By contrast, in the spaceman economy, throughput is by no means a desideratum, and is indeed to be regarded as something to be minimized rather than maximized’ (ibid.: 8). The stock of capital and its maintenance should gain more appreciation by economists, since well-being and standard of living depend largely, though not only, on stocks. Consumption is a means, not an end in itself. Boulding’s brief remarks can be interpreted as tolerable GNP growth according to availability of renewable and recyclable resources and sufficient size of depositories for pollution (sinks).

Another prescient idea is Boulding’s observation of widespread myopia in economics, obsessed by increasing consumption rather than caring for posterity. A key reason is the time and uncertainty of discounting with positive interest rates (including an uncertainty premium) which drives investors to ‘Après nous, le deluge’ (ibid.: 10). The myopia leads economics to promote economic growth to better cope with the problems of the future, instead of acting now (expressly Barnett/Morse 1962). He does not call for zero growth or de-growth but downplays the role of growth for the well-being of societies, similar to Galbraith’s call for more public goods in an affluent society (Galbraith 1958 [2010]).

Georgescu-Roegen, the founder of ecological economics, introduced the laws of entropy into economics which in physics apply only to energy (Georgescu-Roegen 1971; 1976). Georgescu, in contrast to Boulding, applied it to all natural resources, including material or matter and renewable resources. Constancy of output and/or GDP – that is, a steady-state economy (SSE) – would thus be impossible even if population growth were zero. This opens the door to de-growth, although Georgescu-Roegen was aware that solar energy is available in *de facto* unlimited scale of supply, even with no pollution, but with a low degree of efficiency. He saw that constant production can use up limited natural resources, similar to output growth. Although his astute writing and sharp tongue could be understood as a demonstration of the inescapable fate of mankind to be subject to rising entropy, doom and death, he could perhaps be read differently. First and foremost, he battled neoclassical thinking which he considered mechanical and a-historical with its axiom of reversibility of all processes borrowed from physics. So, he debunked Pigou’s statement: ‘In a stationary state factors of production are stocks, unchanging in amount, out of which emerges a continuous flow, also unchanging in

amount, of real income' (Pigou 1935, cited in Georgescu-Roegen 1975: 348). And: 'The myth is that a stationary world, a zero-growth population, will put an end to the ecological conflict of mankind' (ibid.: 349). He put Marx in the same boat as Pigou and the other neoclassicals since Marx mentioned that natural resources come gratis from Earth. In his critique of SSE, he wrote: 'The crucial error consists in not seeing that not only growth, but also a zero-growth state, nay, even a declining state which does not converge toward annihilation, cannot exist forever in a finite environment' (ibid.: 367).

He expressly called for a 'declining state', a term used by Adam Smith, but carefully avoided referring to GDP or GNP. He not only believed in quasi-economic entropy laws but also in the limited substitutability of natural resources by man-made capital or technical progress. Far from denying innovations, substituting capital for nature suggests that capital is something outside nature. He ridiculed the naïve beliefs that technology can replace nature by saying that using two saws instead of one cannot replace limited wood. Yet he saw that immense amounts of solar energy may be available without pollution. In this vein, he criticised the neoclassical concept that technical progress will come, sooner or later, on time – as if it were impossible to be 'too late'; time is understood mechanically and a-historically. True innovations were seen as balancing factors against rising entropy, but he thought they seldom came as mere coincidences of luck.

He most likely underestimated the role of those innovations that reduce the consumption of material resources. Natural resources were differentiated as highly scarce or less scarce or even fully replaceable. Of course, scarce is scarce, no matter whether it is gold, coal, sand, water or land. For practical issues with a non-eternal time horizon, it matters a lot. That the atmosphere might become the scarcest resource on the planet, not mineral resources, especially fossil energies, was not foreseen by Georgescu-Roegen, despite his visionary knowledge of the role of nature. He challenged economics with what he called bio-economics, but the response of the economics profession was mainly to duck out.

Daly stands on the shoulders of Boulding and Georgescu-Roegen. Daly elaborated on the idea of the SSE, in contrast but also in response to Georgescu-Roegen (Daly 1977; 1996). Daly's understanding of an SSE was an economy with constant capital stock plus constant population and a constant low throughput which is seen as more or less similar to output or GDP. Daly presented different definitions in his writings. It is often emphasised that all definitions are entirely in biophysical terms, not in monetary terms of national accounting. Daly started with definitions that focus on constant stocks of capital and constant population with a low rate of throughput (energy and material) commensurate 'with the regenerative and assimilative capacities of the ecosystem' which leave the natural capital stock unchanged; sinks for wastes are seen as part of the capital stock (Daly 1990: 2). Alternatively, an SSE has a constant flow of throughput at a sustainable level, while population and capital stock adjust (Daly 1977). The difference is puzzling. Obviously, there is no constant ratio between capital stock (and population) on the one side and throughput on the other. In the case of a constant ratio, both concepts would be identical. Regarding the flows, three types are discerned: material inputs, energy inputs, and outputs in the form of waste and pollution. Capital is understood in a broad sense. Two scale measures are implied which balance inputs with regenerative capacity and output with capacity of sinks (see O'Neill 2015). This concept has very high information and measurement requirements, which render it almost unfeasible. Throughput, especially, has to be measured, and information about sinks is needed (in the case of the greenhouse effects only since recent times). Ensuing measurement of throughputs was put on the agenda. The best metric for throughput is GDP, as Daly (2014: 222) asserted, so that throughput and output seem to form a constant ratio. This notion is obviously in stark

contrast to the empirical evidence of often falling material intensity of GDP, energy intensity and also GHG intensity of GDP. The same would apply to the ratio of natural capital to GDP. With one hectare of land a value of 10 currency units or 1000 units (inflation-neutral) can be produced, with a constant amount of other natural resources; and with one ounce of gold a bright goldsmith can produce more value of jewellery than a less skilful one. Daly might have ignored what Boulding called ‘information’ in his spaceship economy that is included in production (in more modern terms, ‘human capital’).¹⁰ This objection implies that the growth of information (a.k.a. human capital) can increase GDP as long as no further natural resources are consumed and natural capital is maintained. The potential for ‘green growth’ under these restrictions – and in line with thermodynamics – may be small, but the prospective accumulation of knowledge is fundamentally uncertain.

Daly added three well-known principles for the use of natural resources which can be understood as criteria for ecological sustainability: the use of all resources must accord to the absorption capacity of the ecosystem; the use of renewable resources must not exceed the regenerative capacity of the ecosystem; and the depletion of exhaustible resources must not exceed the capacity to produce renewable substitutes (Daly 1990; 2005). It is not clear whether these criteria are part of (or an addition to) the SSE concept which leads into zero growth. If so, the restrictions on the economy are more tense, depending on technologies to substitute renewable for non-renewable resources. While Daly attempted to camouflage the opposition to Georgescu-Roegen (Daly 1995), Kerschner (2010) was looking for bridges between zero growth and de-growth. As our scenarios for the ecological transition in Section 3 showed, zero growth is by no means *per se* environmentally friendly. If the level of fossil energy consumption is far too high relative to the sinks, either the emission intensity has to fall or else GDP does. This insight gives technological change during the transition to climate neutrality (that is, mass implementation of renewable energy on a global scale) much greater impact than Daly’s quest for zero growth.

While great efforts were made to measure throughput, whether by the metric of weight (tons), with specific coefficients to specific materials, or by land units, less had been researched on the capacity of sinks, either global or regional ones. With the wisdom of hindsight, they seem to be the scarcest natural resource, and not just in the face of the climate crisis. Whatever the proper metric for throughput or for the capacity of sinks might be, there is no clearly identifiable or even constant relationship between GDP and SSE. Yet the judgement is difficult since we do not know in monetary terms – that is, in GDP – what SSE would be. Of course, there *is* a relationship as long as increments of GDP are not totally immaterial, but it seems to be more complex.

4.2 Ecological footprint economics, de-growth and a-growth

This gave rise to various streams of de-growth concepts which first embarked on shrinking GDP until an SSE-compatible level was reached, then more toward an agnostic relationship with GDP: just do what is necessary and see what the GDP outcome is (sometimes called a-growth). Others just used the GDP metric and opted for zero-GDP growth, although it differs from SSE (Jackson 2017; 2021; and the de-growth proponents Kallis 2018; Hickel 2019; Keyßer/Lenzen 2021).

10. He mentioned this point earlier (Daly 1996: 70) but downplayed it as an attempt to promulgate unconditional growth.

The most advanced empirical attempt to measure the use of natural resources of all sorts is the ‘ecological footprint’, which compares the measured biocapacity with the footprints, for individuals, countries and the world (Wackernagel/Beyers 2019; and see <https://data.footprintnetwork.org>). The common metric for all consumption of natural resources – throughput and energy – are ‘global hectares’ of land. The rationale is to reduce complexity and to estimate – with many simplifications – the degree of over-use of natural resources.

The methodology estimates first the biocapacity of the Earth (or regions or countries). It is the capacity of the Earth to regenerate ‘plant matter’. Land is calculated in area metric (ha) for the categories of carbon, built-up land, forests, cropland/pastures and fisheries with global average productivity according to measured yields. Carbon, the most important category, is not the stock of carbon underground in oil, gas and coal, but the amount of forest capacity to absorb CO₂. Thus, forests have two functions in biocapacity: sinks and supply of lumber. Different land types are aggregated with equivalence factors reflecting different productivity. Next, footprints are calculated for the consumption of energy, settlement, timber/paper, food/fibre and seafood. Then the direct and indirect nature content of goods, counted in land units for different consumption groupings, is estimated and compared with the biocapacity. The footprint is a flow, the biocapacity a stock that allows annual resource provisioning. Data exist for all countries since 1961. Aggregate footprints grew almost threefold until 2017, while biocapacity grew only a little. Since 1970, the global footprints have started to exceed the biocapacity; before 1970 there were reserves. In 2019 the global footprint stood 70 per cent above the biocapacity. Three points stand out. (Data in the following paragraphs from data.footprintsnetwork.org and own calculations.)

First, energy use accounts for 60 per cent of the global footprint; in advanced countries around 70 per cent. Most likely other footprints depend indirectly on energy, too. This implies that full decarbonisation of the world would massively reduce the global footprint.

Second, the global footprints rose from 1990 until 2017 by 1.4 per cent p.a., less the increase in the biocapacity (+0.4 per cent p.a.) by around 1.0 per cent p.a. This footprint growth above the biocapacity is less than global population growth (1.5 per cent p.a.) and much less than GDP growth (2.8 per cent p.a.). This means that global footprint growth wouldn’t have emerged without population growth – or, put in other words, it was due to GDP per capita growth, given the population growth trends. Interestingly, global footprint growth is similar to GHG growth, which is the same as population growth in the same period. However, cause and effect may look differently when one looks at the regional disaggregation of footprints, GDP and GHG. Nevertheless, the outstanding impact of population growth is often neglected.

Third, if the footprint metric is considered as a proxy for throughput, then GDP cannot be seen as a proxy for throughput as proposed by Daly since GDP grew so much faster.

The footprint seems to measure aggregate energy consumption (both fossil and renewable as far as CO₂ emissions occur or land is used) and materials (or ‘matter’), hence throughput. The indicator, as rough as it may be, is not more and not less than an indicator for the *pressure* of the economic mass usage of natural resources which have a bearing on many other environmental and social problems. Besides this, it is a popular and easily understandable one. Wackernagel/Beyers (2019) do not even mention GDP in their book, although they call for reduction of consumption which may be interpreted as degrowth of GDP. Their proposal for reducing the ‘footprint-debt’ of 17 ‘planet years’ (in 2016) with overshooting usage of natural resources is astonishing. They plead for technology solutions (not explained), individual saving and allocation of consumption rights

to countries (or regions) or individuals, replicating a former proposal from Daly (quotas for throughput), probably more a kind of rationing than tradable permits. The proposals remain brief and somewhat gloomy. Implicitly, the footprint methodology seems to follow mainly a consumption de-growth strategy, especially in the Global North.

Concepts for *a-growth* were proposed due to discontent with green growth and de-growth. Green growth is understood and rejected as growth with relative decoupling but still rising emissions (brown growth in Victor's taxonomy); concepts for de-growth are seen to be shifting away from GDP as the standard metric and follow diverse directions. Van den Burgh (2011; 2017) proposed a-growth. He distinguishes five competing targets for de-growth: GDP, consumption, work time, physical (throughput) and 'radical de-growth', comprising anti-capitalist and grassroots movements. Following the author, physical de-growth would be similar to proposals from the Meadows et al. (1972) and from Daly, hence 'old wine in new bottles' and similar to GDP de-growth, with environmentally poorly targeted policies and no broad political support. Similar reservations could be made against zero-growth concepts but are not mentioned by the author. His idea of a-growth intends to be agnostic toward GDP and rejects an orientation based on a problematic metric not in line with well-being. Hence, climate policy should follow mitigation strategies and disregard *ex ante* GDP goals, be they positive, high or low, or negative *ex post*. This sounds like a blind flight for economic policy. Nonetheless, *ex ante* targeting of a specific growth rate, be it zero or another rate, is problematic and would require major economic policy change.

De-emphasising GDP and its growth misjudge the role and impact of national accounting. GDP is an overall indicator for the market space for firms and their entrepreneurial strategies, mainly geared to increase profits, improve the competitive status and to gauge the opportunity to accumulate fixed capital. Decisions on fixed investment are the key driver for growth from a Keynesian point of view, for demand and supply on goods markets and to some extent also on labour markets. For the government, GDP growth is the key metric for the growth of tax revenues and for carrying public debt; for the valuation of financial assets, it is the main bridge to the real economy. For trade unions and workers, it is a prime determinant for employment, wages and poverty, apart from productivity. Although GDP is a poor indicator for collective well-being, at least in high-income countries, it shows the aggregated economic performance, which has a strong bearing, at least indirectly, on some important dimensions of well-being. All these factors are key for understanding why GDP growth is considered widely as an imperative for economic policy and its predominance compared to environmental issues. For politicians and probably the vast majority of economists, zero growth is anathema. Zero growth in a closed economy makes by definition aggregate capital accumulation – that is, positive net investment – impossible, thus reducing the size of investment goods production and the level of GDP and employment, as well as the level of profits and profit rates, and requires all net incomes to be consumed or residual savings to be compensated by fiscal deficits.

Standard macroeconomic analyses for maintaining economic and financial stability are rare or absent in ecological economics, as absent as biophysical issues in standard macroeconomics, including all strands of Keynesian economics. With regard to a-growth, it is indeed important to know the tentative economic prospects for GDP, at least as rough estimates, in order to set up policy goals and implement sectoral targets. Especially for the cases of zero growth and GDP de-growth it is paramount to understand how the economic system's stability can be maintained and how deflation, unemployment and crises can be prevented, since these roads incorporate regime changes of grave importance in all areas of the economy and society, comparable to the emergence of industrial capitalism in the early nineteenth century.

My takeaway from the digression on ecological economics is mixed. The concept of SSE in biophysical terms is only coherent if the *level* of output and also technology change is included in the analysis. Zero growth as such is not sufficient for ecological sustainability, and it is not clear whether zero growth should be a biophysical guideline or should apply more or less to GDP. De-growth concepts are quite diverse and are not very clear; the same is true of a-growth. A thorough macroeconomic analysis of zero growth, and even more of de-growth, which includes biophysical issues, is rare or missing, but also in standard macroeconomics. If low or perhaps zero growth could be combined with massive technological change toward decarbonisation, technology has more impact than Daly and other proponents believed. Global low and green growth in GDP terms along the successful 1.5°C scenarios in Figure 2 might deliver the Paris goals. This would likely have strong positive knock-on effects on fighting other planetary ecological risks addressed by natural scientists (cf. Rockström et al. 2009; Steffen et al. 2015).¹¹ Yet zero growth or even de-growth in the Global North could perhaps support the South in the transition, or appear on the agenda after 2050. This issue will be tackled in my conclusions.

5 CONCLUSIONS

Let us assume it is foreseeable that the Paris goals cannot be fully realised on the part of the Global South. Should the Global North – for the sake of avoiding > 2°C pathways – target higher GHG reduction and accept a zero-GDP-growth pathway in the face of much higher GDP per capita in the North, combined with a full transition to renewable energy and other reductions of GHG? This raises the question of the economic consequences of zero growth of GDP in general. With continuous zero growth, capitalism in the usual definition would dissolve in a closed economy, as mentioned above. Wealth owners would have to consume their profits and workers would have to cease saving, following Kalecki (1971; cf. Cahen-Fourot/Lavoie 2016; Fontana/Sawyer 2022; Hein/Jimenez 2022), to maintain macroeconomic equilibrium. Entrepreneurs would transmute into simple commodity producers as in Marx's simple reproduction scheme, would stop accumulating capital, would abandon their animal spirits and would become good consumers instead. Shareholders would become consumers as well, which implies that they would not hold more wealth than they could use for consumption. Stock prices would likely plummet, with reallocation of assets following. Economic and financial stabilisation of a closed zero-growth economy would therefore be a huge challenge for fiscal, monetary and financial market policies.

If the animal spirits of capitalists did not fade away on a grand scale, capitalists would likely attempt to relocate their production to growing economies in the Global South, given cross-border capital mobility. This would lead to export surpluses in the Global North – with the exception of chronic-deficit countries such as the US, which would reduce imports – and would lead to trade deficits in large parts of the South. But external balances would change in the South in any case due to fewer exports of fossil-energy producers and fewer energy imports in the other countries. Furthermore, carbon-based border

11. These authors follow a strictly science-based approach without any link to economic indicators. They see nine planetary boundaries, of which two are in a very critical 'zone' (genetic diversity; biochemical flows, that is, phosphorus and nitrogen), while climate change and land-use change are tending to become critical. The scientists attempt to quantify the risks in the different 'spheres' in an aggregated manner also, but not in the categories of throughput or similar.

fees or taxes would need to be established. Trade and balance-of-payments conflicts would be likely, but with good global governance would perhaps be manageable.

Globalisation would help accumulating capitalism to survive if ever growing global imbalances could be avoided. However, domestic macroeconomic policies would have to change without endangering employment. Residual domestic saving would equal the current-account surplus, if domestic consumption and private investment stopped growing and the budget balance were zero so that GDP remained – possibly with some fluctuations – constant. Structural change toward green growth in tandem with de-growth in brown sectors would leave GDP unaffected. A huge challenge would be stabilising the price level and the financial sector to prevent depression.

Assume now a scenario of GDP de-growth in the Global North during the transition, in order to speed up GHG reduction. De-growth would be a medium-term phase that would likely lead to zero growth in its aftermath. Expected and unexpected de-growth should be distinguished from one another. History shows many examples of shock-like falling GDP, as severe crises or depressions. Orderly restructuring of the capital stock toward decarbonisation is highly unlikely. Yet energy consumption and emissions might drop, such as in the breakdown of the former German Democratic Republic in the first years after German reunification. Without support from outside (as in the case of East Germany), finishing the crisis let emissions recover. *Expected* de-growth of GDP might be different. It would require targeted de-growth in brown sectors with a targeted lower level of consumption to be maintained, and less than compensating growth in clean sectors. Two main problems would emerge: expectations of a downward spiral of shrinkage with a full-blown depression – including deflation and financial crisis – would need to be avoided, and losers of jobs, income and capital would need to be compensated. Such a scenario is unprecedented and highly unlikely to be implementable in democratic societies.

Another de-growth scenario would grow from the grassroots: when the animal spirits of a considerable number of entrepreneurs vanish, new lifestyles with less consumption would be cherished, with a working-time reduction by large parts of the population, perhaps in combination with a shrinking population. This is similar to Keynes's message to his grandchildren, which could lead not only to zero growth but also to a prior phase of de-growth (Keynes 1930). Even if this age came half a century later than Keynes had hoped, most likely it would be too late and too unreliable to reach the Paris goals. Yet, among all de-growth scenarios, this one would be driven by terminating the growth of aggregate consumption, envisioned also by the classical pioneers of economics. Whether it were in line with the requirements of environmental sustainability in the twenty-first century, whether it were intrinsically stable or could otherwise be stabilised remains open to debate. Absent a suitable name for this kind of economy, for the time being let's call it 'post-capitalism'.

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