The economics of climate change – green growth, zero- or de-growth?

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Abstract

The article discusses the ongoing green transition towards climate neutrality in 2050 with a focus on the options of green growth, zero- or de-growth. First, the key facts about the greenhouse effect and the status quo are shown with special attention to the industrialisation of emerging economies as the key contributors to greenhouse gas emissions since about 1980. Second, the features and policies for facilitating the transition are analysed. The carbon price emerges as a key global price that needs public rather than market control. Third, the core debates on the feasibility of economic growth in ecological economics are used to shed more light on the present issues at stake. Finally, the quest for moderate global green growth is confirmed in order to accomplish decarbonization of the planet and terminate extractive capitalism as far as fossil energy is concerned; however, these attempts cannot evade the finiteness of natural resources, including land and renewable resources. The green transition leads likely close to global zero-growth of GDP which would eventually terminate the age of capital accumulation, the heart of capitalism.

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

JEL: O47, P18, P28, P47, Q01

The economics of the green transition and zero-growth

Modelling zero-growth should be done with taking into account four related issues. First, it has to be clarified - *zero-growth of what?* Growth can refer to the gross domestic product (GDP) in the present methodology of National Accounting or to other aggregates such as "throughput" or natural resources in general. Second, the causes why zero-growth is considered necessary or beneficial compared to positive growth or de-growth have to be heeded. If growth dynamics fade away independently due to lack of technical progress or of waning animal spirits of entrepreneurs, policies differ from imposing environmental constraints on GDP if natural resources are over-used. Besides this, conventional environmental policy does not – for good reasons – target GDP growth as an aggregate, but follows specific targets and specific tools. Third, zero-growth – discussed in an ecological framework of a steady state economy (SSE) – needs to be analysed in tandem with the *level* of output which impacts the environmental burden. Often it is assumed, explicitly or implicitly, that "environmental sustainability" is already reached or a "steady state" (both terms subject to many interpretations). If both the level of output and its growth are considered problematic, temporary de-growth can be necessary as the prelude to ensuing zero-growth. Then zero- and de-growth would be twin issues and should be discussed in the same vein. These topics have been analysed since half a century in ecological economics and elsewhere, without a clear-cut result, but were not addressed properly in macroeconomics, including Keynesian economics of all brands until recently. [1] Fourth, analysing zero-growth in a closed economy yields limited insights – even if it is considered as the planetary economy – because the particularities of highly diverse open national economies are of utmost importance.

In what follows, I exclude discussions of reforms of National Accounting and use for the sake of simplicity standard definitions. Furthermore, I address only ecological reasons put forward for the quest for zero-growth or de-growth.

I discuss the issues with a focus on growth in the context of the transition to the so-called climate neutrality until 2050. Starting with wrapping up the stylized facts of the climate crisis, the key

[1] Keynesians of all brands have shown little interest in the ecological debates on growth, with few exceptions (e.g. Fontana/Sawyer 2016, Lange 2018). See the voids in King's (2021) encyclopaedia.

challenges of the "green transition" with high or reduced GDP growth scenarios are analysed. Ensuing, I turn to the perennial debates on limits-to-growth and attempt to filter out proper answers for the green transition and its aftermath. Conclusions follow.

1. 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, scarcity of ecological sinks, lack of arable land and nutrition, water scarcity and food production, the diversity of species and last not least the wellbeing of large parts of future generations of mankind. In the Paris Agreement (2015) the signatory states pledge to the goal of limiting global warming to "well below 2°C" above the pre-industrial temperature and strive for reaching the 1.5°C target by 2050. The declaration refers to all greenhouse gas emissions (GHG) which shall be lowered to a level that is in balance with the natural sinks, hence not necessarily zero. Peak GHG shall 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, the debates focussed on eradication of CO2-emissions until 2050 and climate neutrality, a term open to many interpretations, while methane-reductions were less high-lighted. It is often conceived as "negative emissions" of GHG may be allowed to some extent, especially after 2050 (cf. Fuss et al. 2018).

The 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 67% probability has a size of 400 Gt CO2, and 1,150 Gt to achieve the 2-degree goal by 2050. If the present global CO2-emissions are estimated at close to 40 Gt p.a.[2], the 1.5-degree budget would be used up in 10

[2] 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 Mega tons (Mt), excluding emissions due to changes in land-use and forestry (LUCF). I assume CO2-emissions in 2020 at around 40 Giga tons (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% of GHG, nitrous oxygen (N2O) for 6.3%, F-gases for 2.3%; net LUCF are estimated at 2.8% (data for 2018 from CAIT retrieved on 7 October 2021).

years, the 2-degree budget in 29 years. Global warming by +2°C cannot exclude that crucial tipping points for the world climate are triggered. IPCC uses as complementary goals reduction scenarios for methane and the other gases. Methane-emissions should be halved until 2050 according to IPCC in the most ambitious scenario (2021, scenario 1-1.9, 17). 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 average 9 years), GHG-emissions cumulate. If so-called negative emissions after 2050 are to be avoided, climate neutrality means that all GHG emissions have to be stopped. Technologies or policies for negative emissions such as Carbon Capture and Sequestration (CCS) or geo-engineering are considered critical by most climate experts (e.g. UBA 2019, 6; SRU 2020, 62f., Edenhofer/Jakob 2019, 64, Pfluger et al. 2017 calling for 95% CO2 reduction, Holz 2018). 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 2019). Debates are ongoing.

GHG and GDP dynamics

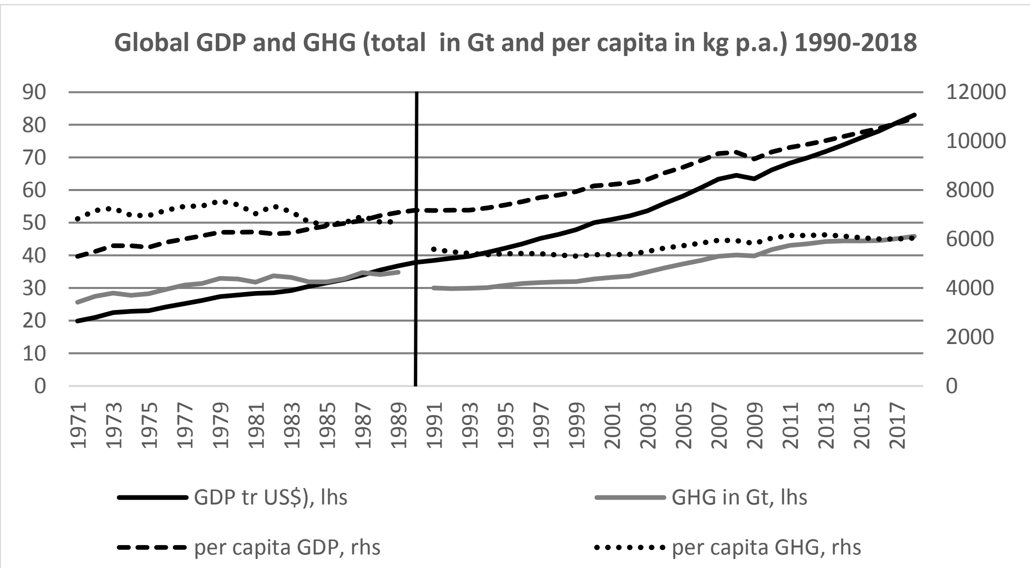
In the period 1990-2018 global GDP (in constant 2010 US$)[3] grew by 2.8% p.a., while the world population grew with a rate of 1.3% so that GDP per capita rose by 1.5% p.a., almost as fast as GHG-emissions with nearly 1.6% p.a. Light relative decoupling of GDP and GHG did occur, but no absolute decoupling (Figure 1). The average growth rate of CO2-emissions (incl. LUCF) is the same as for GHG in this period. GHG emissions have not yet reached a peak (let alone the small dent in 2020 due to the Covid19-crisis), actual data for 2020 still missing. Almost half of GDP growth was driven by population growth. The emission intensity – GHG emissions as a share of GDP – reduced by nearly 1.3% p.a. at a far too slow pace. If the global GDP would drop by 50% 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 would be applied – this is a bit more than halving global emissions of 47.5 Mt in 2018, far too little for reaching the 1.5°- or 2°-goal. In other words, without speeding up the reduction of GHG intensity, by

[3] Data using constant PPP US$ show higher growth rates for developing and emerging economies. PPP data rely on several assumptions, among others a constant ratio of PPP-based GDP to GDP in constant US$ over a long time span. Therefore, I prefer using GDP data in 2010 constant US$.

new technologies and/or changed behaviour of consumers, even heavy de-growth of GDP cannot do the job. It is the far too high GHG-intensity of the predominant mode of production which is at the root of the climate problem, aggravated by population- and GDP-growth. The need for speed in climate policy echoes the speed of the build-up of the pollution in the atmosphere. Cumulated GHG-emissions grew by not less than 13.6% p.a. from 1990 until 2018.

The relationship between GDP per capita and CO2 per capita shows great variance across countries. At the global level in 2018, GDP per capita was – in constant 2010 US$ - 4 ,785 p.a. while average CO2 was 4.5 tons per capita, reflecting a very high CO2-intensity of output. 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 p.c. of US$ 54,900, while Germany with 15% lower income per capita caused 44% less CO2-emissions (8.5 t per capita). Even more telling is the comparison of Poland and Germany: both countries emitted almost the same amount of CO2 (8.5 and 8.3 Germany vis à vis Poland), but Germany's GDP per capita is 2.8 times higher (2018). China`s CO2-intensity was 5 times higher than Germany's, although Germany has a mediocre rank compared to champions like Sweden or Switzerland. Obviously, there are enormous differences in CO2-intensity, both amongst rich countries and amongst rich and poorer countries. The key point here is that most countries in the Global South use fossil energy as primary energy source (often coal) and for electricity generation, many rich countries do the same. On the global scale, fossil energy made up for 84.3% of primary energy consumption and 63.3% in electricity generation (2019).

Figure 1



Source: WDI with GHG data from CAIT. Note: GDP in constant 2010 US$. Until 1990, data for GHG were based on a different methodology causing a break in 1990.

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)? In 2018, one third of global emissions came from the North, two thirds from the South (with China emitting 26% of global emissions).[4] The increase in global GHG emissions in the period 1990-2018 was 54%, but only 4.2% in the North and 99% in the South. 57% of the global increase was made in China, 27.6% 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 in the North are the twin parts of the pincers which 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 would 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 looming.

From a historical perspective, it is notable to be aware that from all fossil energy (coal, oil and gas) burnt since 1896 until 2019, 50% were burnt since 1991 (Wackernagel and Beyers 2019, 6). This marks shared responsibility of the global North and the global South.

Summarising these brief facts about the climate crisis makes clear that the problem is not due to exhausted fossil resources; in contrast, there are still abundant fossil resources in the earth which must not be used and need to be preserved as a treasure for the earth.[5] The true resource constraint is the limited capacity of natural sinks for absorption of GHG. Warming of the atmosphere is a result of the emergence and perpetuation of extractive capitalism since the industrialisation of Europe, based on exploitation of nature and labour, replicated by emerging economies since around 1980. GDP growth alone cannot explain the crisis, technology and structural change with excessive pollution intensity are involved as well, accompanied by the

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[4] All data in this paragraph are from WDI 2021 unless noted differently.

[5] Edenhofer and Jakob (2019, 74) report that the global fossil energies under the ground are estimated at 15,000 Gt CO2.

competition of nations rather than their cooperation. Macroeconomics with a focus on aggregate demand dynamics cannot capture the clue of the crisis unless they embrace structural change, technology and the supply side of production.

3. The economics of green transition

3.1 The main features of the transition

Green transition in this context means full decarbonisation and reduction of all GHG-emissions down to a very low level so that compensation of negative emissions can be avoided. The "net zero" is then zero CO2-emissions in the year 2050, hence GHG-emissions must not rise but be curtailed by 50 Gt or 1.66 Gt p.a. if a linear pathway is assumed. In the beginning this implies a reduction of 3.4%, rather than 1.26% in the past trend. 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 in unknown size will emerge after 2050; they have to be captured with not-yet-existing "Carbon Dioxide Removal" (CDR) with CCS (CO2 is separated in production processes and stored underground), Direct Air Capture (DACCS), Bio-Energy Capture (BECCS) or Geo-Chemical CDR or by afforestation. Several scenarios of IPCC include negative emissions after 2050. Many authors warn against CCS or recommend to give clear preference to curbing emissions.

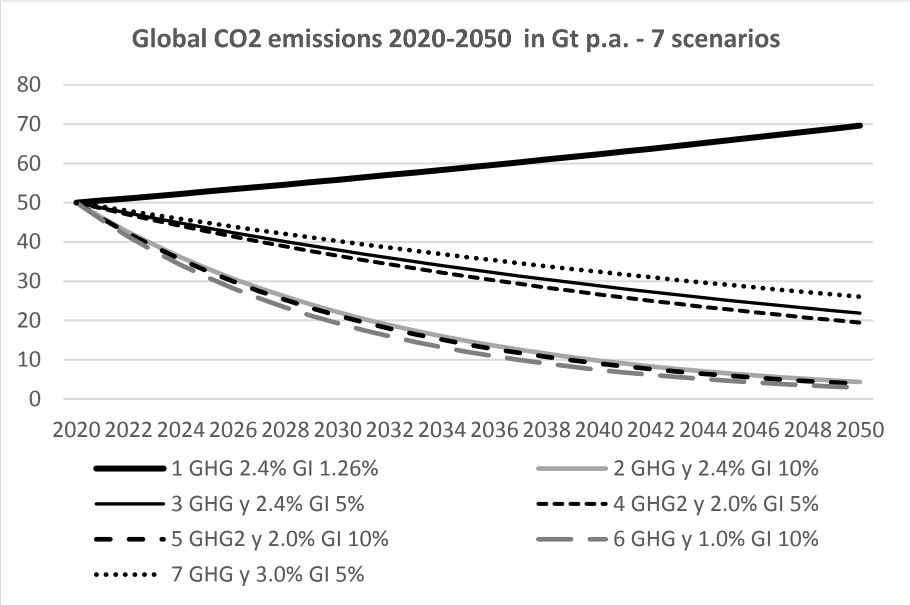
Seven scenarios

The expected GDP and population growth in a status-quo-scenario has to be taken in account. The OECD expects a slight slow-down of world growth mainly in the South due to maturing emerging economies toward a rate of 2.56% p.a. 2020-2050 (OECD 2018). I assume a slightly more moderate growth rate of 2.4% for the world, which is 1.5% for the North and 3.5% for the South.[6] Global population growth is forecast by UN-DESA (2019) by 0.74% in the medium-variant (and 0.44% in the low-variant, with 9.7 bn and 8.4 bn in 2050, respectively, compared to 7.8 bn in 2020). This leads to a per-capita GDP growth of 2.78% p.a. in the South and 1.34% 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%). Regarding GHG-emissions,

[6] While the GDP of the Global North was in 2020 63% of the world GDP in constant 2010 US$, it would be 48% in 2050, given these assumptions.

everything hinges on the speed of reduction of GHG-emissions, if GDP growth follows the trend (see Figure 2). I assume that GHG emissions in 2020 have reached around 50 Gt (after 48.9 Gt including LUCF in 2018) as the starting point for all scenarios.

Figure 2



Source: author. Note: GI is the reduction rate GHG intensity, y is GDP growth, both p.a.

Scenario 1 in Figure 1 shows business-as-usual, with slightly reduced trend growth and GHG-intensity falling with the past-trend rate of 1.26% p.a. This leads to GHG-emissions of 64 Gt in 2050, 39% more than 2020. It is a no-go-pathway leading into climate disaster. One bundle of trajectories with three scenarios delivers mediocre results (# 3,4 and 7) which about halve emissions by 2050 compared to 2020. The other bundle with three scenarios reaches the target (# 2, 5 and 6) assuming that some non-CO2-emissions remain in the size of 3-5 Gt which corresponds to GHG reductions of 92 and 94%, respectively. The lower the GDP growth rate, e.g. 1.0% p.a. in #6, and the higher the GI-rate, e.g. 10% p.a., the smaller the remaining GHG gap in 2050. Even #2 with 2.4% growth and 10% GI-improvement p.a. differs not much from the #6 with 1% growth. 1% GDP growth boils down to almost zero-growth in per-capita terms.

Table 1

Scenario	Residual 400 budget consumed	cumulated CO2 2020-2050, Gt	CO2 reduction 2020-2050, %	GHG change 2020-2050, %	1.5°/2.0° reached

1 y2.4 In1.26	2029	1118	-7.8	39.3	no
2 y2.4 In10	2041	440	-91.4	-91.4	almost 1.5
3 y2.4 In5	2031	792	-56.3	-56.3	2° ?
4 y2.0 In5	2031	754	-61.1	-61.1	2° ?
5 y2.0 In10	2043	425	-92.3	-92.3	almost 1.5°
6 y1.0 In10		391	-94.3	-94.3	1.5°
7 y3.0 In5	2030	855	-47.9	-47.9	no

Source: Author. Note: In is CO2 intensity of GDP

Table 1 shows the CO2-reductions or increases in the same seven scenarios, compared to the Paris-goals and the residual CO2 budget of 400 Gt CO2 for the 1.5° goal and 1,150 for the 2° goal. The same scenarios as above reach the criteria for the 1.5° trajectory (#2, 5 and 6). With 2.4% growth trend a reduction of CO2-intensity (In) of not less than 10% p.a. is necessary, to achieve a reduction of 91.4% 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% growth pathway with also 10% efficiency increase reaches 94.3% reduction. Residual CO2 and GHG remain in 2050 since the trend of intensity-reduction reaches zero asymptotically. Comparing scenarios #2 and #5 demonstrate that a lower growth rate is helpful, but the change of the intensity plays a more important role, especially if strong reductions come upfront. The other scenarios are far off the goals, except that the 2°-budget is not yet used-up in 2050 in all these trajectories, but #3 and 4 could reach the 2°-goals only with strong leaps after 2050. That a rest of the GHG-emissions, other than CO2, still remain in 2050 is in line with the Paris-goals.

The key question is how fast the pollution intensity can be changed. At first glance, GI is a technology-variable, but also behavioural change impacts GI, and most technology improvements require behavioural accommodation, like accepting masses of windmills in the neighbourhood or accepting higher prices for renewable energy.

Green growth in the transition?

Decarbonisation has to relinquish the old capital stock based on fossil energy (FE), and replace or enlarge it by a new capital stock based on renewable energy (RE). The transition is a process of creative destruction, but the open question is whether the change leads to growth acceleration, is growth-neutral or decelerates growth. In the first case, green transition growth contributes to massive modernisation in all countries, especially if done with high speed in the first phase. But high speed means also high destruction of the fossil capital stock. The switch from FE to RE leads to an increase of 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 starting in Europe and North America at the end of the 19th century. Traffic and heating/cooling of buildings will rely mainly on RE-based power generation, if more difficult PtL (Power to Liquid) is excluded or delayed since technologies are not yet sufficiently mature and most likely extremely dependent on mass-scale RE with low EROI (energy return on energy investment). Broad-based electrification requires the redesign of many manufactured products, not only of cars. If the RE-transition in the power generation, in buildings (both construction and heating/cooling), in industry, in traffic and also in agriculture gets momentum, a kind of Kondratiev-boom might emerge which could jeopardise the Paris-goals via rebound effects based on accelerated growth of the world economy. If the transition is delayed due to many obstacles and path-dependent policies, or vested interest of fossil industries, growth acceleration is avoided but the transition retarded. The dilemma could be mitigated or avoided by a lower growth trend and with growth-neutral specific "structural reforms" which can increase the quality of life. Another related pathway is the promotion of energy saving in all areas which would dampens the demand for electricity. While some authors expect a tripling of electricity demand on the globe (McKinsey & Co. 2020), others propose a broad array of energy saving measures which could reduce energy demand by 40% even with an increased quality of life (Grubler et al. 2018).

If we assume that the emerging new energy system does not change the macroeconomic capital coefficient, then any growth rate of GDP involves net investment, i.e. a rising capital stock, even if GDP per capita growth is zero but population grows. The replacement of the old capital stock would change in substance, but not in quantity. Therefore, the transition involves green growth due to a wave of broad-base re-investments. It would be a re-investment boom with accelerator and multiplier effects. If the old capital stock were replaced prematurely, e.g. due to high carbon taxes, the capital coefficient would increase because the lifetime of fixed capital is curtailed. This tends to raise the level of GDP, other variables unchanged.

However, it seems 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 had a smaller size than under a pathway with a higher growth rate. While global GDP doubles with a 2.4% growth in the period 2020-2050, it rises only by one third if growth expands by only 1.0%. 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.[7] Redistribution from the wealthy to the low-income people would raise consumption and the requisite capital stock, seemingly a dilemma.

Under a purely ecological perspective even a continuously shrinking economy in terms of GDP would ease the transition. Such trajectories seem tempting. Why not go in this direction? 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 together with decarbonization. Furthermore, as shown in Figure 2, lower growth alone is only conducive to the decarbonization goal if coupled with a strong reduction of GHG-intensity with new technologies. If switching to a lower growth path or to zero-growth is advised, at least three questions have to be answered. First, lower growth implies high opportunity costs if higher growth would be valued as welfare-enhancing, at least to a relevant extent. If using cheaper and environmentally friendly technology, why not chose a win-win option? If higher growth is believed to more harmful than lower growth, couldn't it be changed and restructured to truly increase welfare, perhaps including re-distribution of income? Second, assessing the likelihood that the low-growth trajectory is more beneficial involves also many uncertainties, heterogeneous norms of valuation and might be more difficult to implement. Third, since we do not know much about the growth trajectories and their implications ex ante, how to choose? Who guarantees that 2%-growth trajectory is not 3% ex post and not zero? Obviously, we need to search for decision criteria in the first place. I will argue below that we should secure, first and foremost, safe "guard rails" for environmental minimum standards and then manage the

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

economy within these constraints. This implies giving these constraints priority against other goals if they are the natural base for everything else.

Many analyses of the climate crisis refrain from raising the question: how could it happen? A common answer given is: negative external effects that were not internalised. This is true but shallow Pigouvian microeconomics. To use this concept requires in the first place knowledge about the damage and quantifiability. Scientific knowledge about the anthropogenic greenhouse effect exists since the end-1970s, foreboding certainly earlier. It is likely that there are systemic forces that make delays in prevention possible, hence structural myopia built-in in the market system via discounting future costs with positive interest rates (cf. Boulding 1996, see below). Grand-scale intertemporal misallocation of resources occurs. That externalities can be irreversible is an excluded possibility in theories of externalities. Also, that collective-action costs emerge when common pools exist, well-known. Moreover, one grand externality triggers multiple other externalities. The most import one is that the entire price system is flawed if key prices like energy prices are undervalued (fossil energy gratis, as Marx observed, except rents and extraction costs, and also undervalued costs of damages). This triggers a false metric for measuring technical progress with pervasive consequences. All this is not simply a special market failure, it is a cascade of failures, deeply rooted in the market system which requires deeper therapies, since simple internalisation is not possible.

Technology change and GDP

In the period 1990-2019, primary energy consumption, counted in TWh, grew globally by 1.9% p.a., almost one percentage point less than GDP, but electricity consumption grew faster, almost in line with GDP (data from ourworldindata.org). Conversely in advanced countries, electricity grew much slower than GDP. If RE energy becomes more expensive than in the past, perhaps also some energy-intensive products and services, disposable income for non-energy goods shrinks, relatively or absolutely. It is unlikely that a better climate emerges without costs, even though some renewable energies are even at present cheaper than FE-based energy and related products. If this holds true, consumption for other goods and services would be dampened. Yet, price elasticities of final demand may differ for different products, between different income groups and across countries. Many unknowns are involved in all forecasts.

There is a systematic problem of transposing complex technological change into National Accounting categories. Even the most advanced science-based research for decarbonisation does not translate technology, regulatory and behavioural change in economic categories. Grubler et al. (2018) who plea for a reduction of electrical power generation by 40% or Wuppertal Institute (2020) in a study on behalf of "Fridays for Future" to make Germany climate-neutral by 2035 – they make not a single reference to macroeconomic data as if there were no relationship between GDP and energy. Of course, there is an interdependence, but it is obviously too complex for capturing it reliably, especially if new unknown technology and change in behaviour is involved, thus leaving much space for speculation.

Are high rates of reducing GHG-intensity possible? Large parts of RE technology exist already with proven feasibility, so that the old capital stock could be replaced quickly. However, RE is embedded in a specific infrastructure, comprising grids, locations, charging stations and many regulations. The necessary change of the global energy production and consumption system is based in important parts on existing technology, but in critical parts on undiscovered or untested technology. This concerns mainly the hydrogen technology based on electrolysis. Production of synthetic fuels for usages where electricity is not applicable is urgently needed for decarbonisation but still in fledgling stages. The survival of aviation hinges on it, certainly a key for economic globalisation. Energy technologies with a low energy conversion efficiency are so land-intensive that energy autarky is critical, at least in the global North. Trade of land-intensive energies would violate the rising energy needs of exporters in the South.[8]

One should be aware that reducing the scarcity of natural sinks with RE-technologies increases the scarcity of other natural resources, especially land and rare metals. The general fundamental issue is whether RE is itself tied to natural constraints and not infinitely producible on a planet with natural boundaries.

Two key open economic issues remain in this section. One is about implementing lower growth (or de-growth) if it is given preference, the other is about the natural constraints for renewable natural resources, in our case energy. I return to these points when consulting ecological

[8] Despite these critical points, German environmental authorities, based on vast technological advice, assert the feasibility of achieving the Paris-goals until 2050 (cf. UBA 2019 and 2021, Pfluger et al. 2017, SRU 2020) for a country with high per-capita emissions, at least to 95% CO_2-reduction. Impacts on GDP-growth are intentionally excluded from these analyses.

economics below. Prior to that it must be clarified whether (and which) tools exist to implement a green transition on a global scale, that is for an unprecedented task of mankind.

3.2 Policies and tools for the green transition

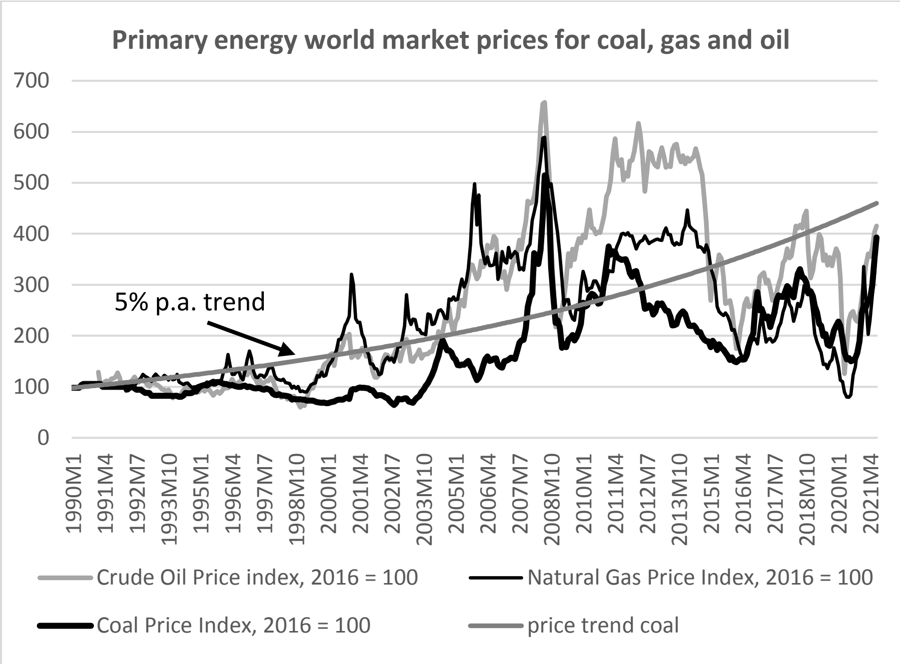
Presently 20% of the global primary energy uses renewable sources and nuclear energy, 29% in electricity production, the remainder is based on carbon, that is 80% and 71%, respectively. In other words, the energy sector (primary and secondary energy production and distribution) of the world, comprising probably 5-10% of GDP (own estimation), is still excessively carbonised, and in most countries relying on fossil imports, the flip side of exports from few heavily fossil energy dependent economies. 60% of GHG emissions originates in the 10 largest emitters which could, in principle, cooperate as trailblazers for the transition, despite their heterogeneity (China, USA, EU, India, Russia, Japan, Brazil, Indonesia, Iran and Canada), while the first four emit 53%. The other 187 signatory states of the Paris Agreement might become followers. Five sector policies have to be implemented in a coordinated manner: for the energy sector (mining/drilling and generation of electricity plus synthetic fuel), industry, agriculture and forestry/fishery, buildings and traffic. The key overarching policy tool is supposed to be a single instrument, the driver for all other tools: the carbon price, either by taxing carbon or indirectly by emission trading systems (ETS) or hybrid pricing (cf. ICAP 2021, OECD 2018). The simple guiding idea is to make carbon energy more expensive than RE and provide governments with new revenues for restructuring and social compensation of energy consumers. Decarbonisation is seen as an allocation system to be cured by efficient prices leading to grand substitution of energy sources. Energy saving is indirectly included if RE becomes sufficiently expensive, hence less cheap than it could be if RE would reach full cost-competitiveness against FE. The reallocation logic excludes macroeconomic and/or macro-ecological solutions by definition. The logic of competitiveness applies within countries between different energy sources, and across countries. The latter implies border adjustment fees or customs which would deeply change global trade. The "carbon border adjustment mechanism" (CBAM), as it is called by the European Commission, would serve as a sanction against non-compliant signatory states. It was the lack of sanctions and the exclusion of developing and emerging countries which contributed to the failure of the Kyoto Protocol; the Paris Agreement attempts to avoid the dilemma between cooperation and competition.

Many economists, most prominently Nicholas Stern and Joseph Stiglitz, the speakers of an expert group commissioned by the World Bank and the IBRD (Stern/Stiglitz 2017) called for an agreement on carbon prices at the level of 40-80 US$ per ton CO_2e in 2020 and 50-100 US$ in 2030. The lower margins are meant for developing and emerging economies, the higher for OECD countries. They found that at the time of writing 85% of global emissions were not taxed, and for the rest the tax was below 10 US$. The IMF reports that the global average CO_2 price is presently merely 3 US$ (IMF 2021, 5). Stern/Stiglitz and others emphasize that pricing directly or indirectly must be embedded in many other tools and regulatory frameworks. Nordhaus (2015) called for "climate clubs" as leading nations, the IMF (2021), fearing trade wars, proposes agreed price floors for large emitters.

The trust in the price mechanism as the key to decarbonisation has several downsides. Five shall be addressed here.

First, both carbon taxes and ETS would make carbon more expensive relative to the world market price of coal, oil and gas. But the latter would fluctuate with excessive peaks and troughs as in the past, depending on unstable cartels on the one side and on speculation with derivatives on the other. Furthermore, the past experience with the EU ETS with CO2 emission licenses since 2005 was not fully encouraging. Prices fluctuated heavily, too many licenses were issued, only industry and power plants were included. The price trend is not foreseeable and disorients consumers and investors; the world markets for fossil fuels are highly distorted by oligopolist competition of mostly state-own-corporations aligned to the national interests of the key players. Alternatively, Schulmeister (2020) proposed a variable tax on coal, oil and gas in the EU with moderate but continuous annual price increase so that fossil energy prices follow a predictable trend and repel the influence of global market fluctuations (see Figure 3).

Figure 3



Source: IMF 2021a. Oil: simple average of three spot prices; Dated Brent, West Texas Intermediate, and the Dubai Fateh; gas: includes European, Japanese, and American Natural Gas Price Indices; coal: includes Australian and South African Coal. Note: 5% is chosen only for demonstration.

Second, another downside of uniform carbon pricing to spur substitution is the fact that energy markets are highly regulated by national authorities, often via state-owned enterprises, subsidies, prices that cover often only variable costs, local or provincial monopolies and the goal of defending national energy security. Often the price elasticity of demand is low. Other considerations play a role, apart from vested interests of mining companies and their shareholders; sub-soil energy reserves are mostly regionally concentrated and downsizing can cause severe regional unemployment with strong political repercussions. Downsizing fossil energy industries would impact stock markets, but shareholders likely attempt to defend their stock prices. These reservations call for broader planning tools, than hoping that “correct prices” incentivise markets to do what needs to be done.

Third, border adjustment mechanisms are key ingredients of managing global carbon pricing when adjustment speeds differ between countries. Detecting the CO2-content in inputs and value-chains is a highly complex undertaking. Uniform regulations under the authority of the WTO or another global organisation are of paramount importance otherwise “carbon leakages” blunt high carbon prices.

Fourth, specific RE-based energies such as hydrogen-based fuels will likely be very expensive even if solar energy is cheap, due to the unfavourable EROI. Carbon-free cement or steel cannot compete with conventional products. Carbon taxes can hardly be ratcheted up to an extent that makes RE-based products in this segment cheaper. Special regulations are needed.

Fifth, even if carbon price increases occur, RE requires often high upfront investment costs and low-interest long-term loans which are not available in many developing countries. Public support for infrastructure, R&D and social compensations are indispensable.

Despite these caveats, the notion that specific international prices like those for fossil energies need to be administered at a targeted level, that unregulated chaotic market prices need to be neutralised, in combination with containing fossil energy quantities, would be a revolutionary change in the system of free-market capitalism. It implies that macroeconomic steering, even on a global scale, should not only target interest rates, taxes, exchange rates, current account balances, but also key global commodities. That is an enormous extension of the traditional Keynesian agenda and could be understood as a specific "socialisation of investment" that Keynes had – in different contexts – in mind since it requires a coordinated restructuring of all national energy systems.

Obviously, the ecological aims of the transition could be reached easier with zero- or de-growth until 2050. Why not? For this reason, I consult now ecological economics before I return to the transition.

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 marginal productivity of capital and other not very clear reasons, Mill hinted to population growth and limitation of land, hence declining marginal productivity of capital and falling profit rates. Also, Keynes envisioned fading appetite for profit accumulation, without any mention of natural constraints. Neoclassical growth theory pushed land and other natural scarcities aside – all the reasons of the classics – and focussed on factor substitution, technical progress and population growth; should the latter two factors wane, growth might run dry and morph into stationarity, no reason to fuss. None of these theories, including microeconomic resource economics, is capable to understand the role of nature for economic development or foresee pending disasters such as climate change.

I will now review in a very brief manner a few prominent authors from ecological economics, namely Boulding, Georgescu-Roegen and Daly and come then to postgrowth theorising.

Boulding (1966) called for a turnaround in seeing our economies as illimitable planes, as frontier economies or "cowboy economy": "reckless, exploitative, romantic, and [with] violent behavior" (7); instead, the planet should be considered as "spaceship earth". The latter has no inputs from outside, apart from 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 even a 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. 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." (8) The stock of capital and its maintenance should gain more appreciation by economists, since wellbeing 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 the posterity. A key reason is the time and uncertainty discounting with positive interest rates (including uncertainty premium) which drives investors to "Après nous, le deluge". The myopia leads economics to promote economic growth to better cope with the problems of the future, instead of acting now (expressly Barnett and Morse 1963). He does not call for zero-growth or degrowth but downplays the role of growth for the wellbeing of societies, similar to Galbraith's call for more public goods in an affluent society.

Georgescu-Roegen, the founder of ecological economics, introduced the laws of entropy into economics which apply in physics only to energy (Georgescu-Roegen 1971, 1976). Georgescu applied it to all natural resources, including material or matter and renewable resources, in contrast to Boulding. Constancy of output and/or GDP, i.e. a steady state economy, is thus 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 low degree of efficiency. Georgescu 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 reversability 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.” (ibidem, 349) He put Marx in the same boat with Pigou and the other neoclassics 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.” (ibidem, 367)

He expressly called for a “declining state” but avoided carefully to refer to GDP or GNP, It is not only his belief in quasi-economic entropy laws but also in the non-substitutability of natural resources by man-made capital or technical progress. Far from denying innovations, but 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-historical, similar to Post-Keynesians critics. True innovations were seen as balancing factors against rising entropy, but he thought they come seldom 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 in highly scarce and less scarce or even fully replaceable. Of course, scarce is scarce, no matter of 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 globe, not mineral resources, especially fossil energies, was not foreseen by Georgescu-Roegen, despite his visionary knowledge on the role of nature. He challenged economics with what he called bio-economics, but the response of the economics profession was mainly ducking out.

Herman Daly stands on the shoulders of Boulding and Geourgescu-Roegen. Daly elaborated on the idea of a SSE, in contrast but also in response to Geourgescu-Roegen (Daly 1977, 1997). Daly's understanding of a 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 emphasized that all definitions are entirely in biophysical terms, not in monetary terms of national accounting. Daly started with definitions which 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…"; alternatively, SSA 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 case of a constant ratio both concepts would be identical. Regarding the flows, three sorts 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 infeasible. Especially throughput has to be measured, and information about sinks is needed (in the case of the greenhouse effects only since recently). Ensuing, measurement of throughputs was put on the agenda. At times, the term throughput was used quite airily and confusing. Aggregation of materials is difficult, even more the addition of materials and energy.

Daly added three important principles for the use of natural resources which can be understood as criteria for ecological sustainability: use of all resources must accord to the absorption capacity of the ecosystem; use of renewable resources must not exceed the regenerative capacity of the ecosystem; 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. 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) is looking for bridges between zero- and de-growth.

While great efforts were made to measure throughput, be it by the metric of weight (tons) with specific coefficients to specific materials, be it by land units, less had been researched on the capacity of sinks, global or regional ones. With the wisdom of hindsight, they seem to be the scarcest natural resource, not only in face of the climate crisis. Whatsoever, taken ecological economics strictly by their words, there is no stringent or even constant relationship between GDP (or GNI) and SSE, neither for the level of GDP (no specific level of GDP for SSE) nor for GDP growth, say zero-growth or less or more. Yet, the judgement is difficult since we do not know in monetary terms what SSE would be – there is no dictionary for translation. Of course, there *is* a relationship as long is increments of GDP are not totally immaterial, but it seems to be more complex. This gave rise to various streams of de-growth concepts which first embarked on shrinking GDP until a SSE-compatible level is reached, then more toward an agnostic relationship to 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 2013, 2021, and the de-growth proponents Hickel 2019, Keyßer/Lenzen 2021, Kallis 2018).

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 and Beyers 2019). The common metric for all consumption of natural resources – throughput and energy – are "global hectares" of land. The rational is to reduce complexity and estimate – with many simplifications - the degree of over-use of natural resources.

The methodology estimates first the biocapacity of the earth (or regions, countries). It is the capacity of the earth to regenerate "plant matter". Land is calculated in area metric (ha) for the categories 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 the 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/fiber 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 until 2016 threefold, the biocapacity grew only a little. Since 1970, the global footprints started to exceed the biocapacity, before 1970 there were reserves. In 2019 the global footprint stood at 1.7 of the biocapacity. The most interesting point is that energy use accounts for 60% of the global footprint, in advanced countries for around 70%. Most likely other footprints depend indirectly on energy too. This implies that full decarbonisation on the world would massively reduce the global footprint unless other factors compensate the improvement due to population growth and growth of material consumption.

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 do not even mention GDP in their book, although they call for reduction of consumption which may be interpreted as de-growth of GDP. Their proposal for reducing the "footprint-debt" of 17 "planet years" (in 2016) with overshooting usage of natural resources is astonishing. They plea 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 as brief as gloomy.

My takeaway is that the green transition may perhaps not lead to some kind of (not well-defined) steady state, but bring a huge amount of less economic and ecological pressure which has positive knock-on effects on fighting other planetary ecological risks mentioned by Steffen et al. (2015)[9] if one of the successful scenarios in Figure 2 can be accomplished; Those with

[9] These authors follow a strictly science-based approach without any link to economic indicators. They see 9 planetary boundaries of which 2 are in a very critical "zone" (genetic diversity, biochemical flows, i.e. 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" also in an aggregated manner, but not in the categories of throughput or similar.

moderate growth which is close to zero per capita growth in the North and slow growth in the South. In particular, if less aggregated energy were used, also less renewable, it can impact the use of material. Material inputs in production always require energy in the production process. From this angle, dampening use of energy and material/matter are complementary.

5. Conclusions

Let us assume the Paris-goals can foreseeably not be fully realised on the part of the Global South. Should the Global North – for the sake of avoiding > 2° pathways – then target higher GHG-reduction at the expense of lower growth rates, be it zero- or de-growth, in face of much higher GDP per capita in the North? This raises the question of the economic consequences of zero-growth and de-growth of GDP. With continuous zero-growth, capitalism in the usual definition – including profit maximising and accumulation of fixed capital – would cease to exist. Wealth owners would have to consume their profits and workers cease saving, following Kalecki (cf. Cahen-Fourot/Lavoi 2016), to maintain macroeconomic equilibrium (in a closed economy). Like in Marx' simple reproduction scheme, simple commodity producers, willingly or coerced, do not accumulate capital, and aggregate saving is zero. But stock prices will likely plummet, reallocation of assets follows. If the animal spirits of capitalists do not fade away on a grand scale, capitalists would likely relocate their production to growing economies in the South, given cross-border capital mobility. This leads to export-surpluses in the North and trade deficits in the South, likely followed by exchange rate turbulences which might reinforce North-South capital movements. Yet, trade conflicts are pre-scheduled.

Similar could occur with de-growth in the North, but in more forceful intensity including a likely breakdown of stock prices and the risk of a full-blown financial crisis contrasting the notion of most de-growth proponents. Fighting depression with deflationary pressure like in historical depressions is more difficult the longer de-growth persists. Although profit rates on average would remain positive – profits would fall in tandem with the capital stock – some or many entrepreneurs will shrink their output strongly or prefer bankruptcy in order to live from their wealth. To avoid an excessive fall in production below what is needed, it is likely that ownership has to be changed, be it toward non-profit state- or employee-ownership or similar.

Imagining an investment function for modelling such processes is difficult or impossible if gross investment falls below depreciations.[10]

All we can say is that the economies in de-growth mode suffer extreme uncertainty; de-growth other than crisis is unprecedented. A faint analogy might be the breakdown of the GDR-economy in East Germany in the first years after opening the Berlin wall 1990-1992, managed with massive state-interventions of all sorts, including huge working-time reductions normally alien to market economies. That spell of half-orderly de-growth was short and for many a nightmare, and it came unprepared as a shock, however with strong environmental relief. This differed a lot from experiences of long-standing zero-growth in advanced countries like Japan and Italy. Gradual and moderate de-growth may involve fewer social hardships. Nevertheless, the myth of an occasionally heard de-growth buzzword *"less is more"* may be misleading and ignoring economic history. Therefore, many postgrowth authors prefer to shun the GDP-footprint of de-growth which is however necessary for the economic analysis which is then shunned too.

Finally, I consider what comes after a more or less successful decarbonisation, be it in the North or in the South. Is the green growth period of the transition the prelude to zero-growth? Very likely it is unless new basic innovations in renewable energy emerge. The transition would replace the burning of fossil energy by renewable energy of all kinds. Renewable resources do not grow infinitely – see ecological economics – as they require non-renewable inputs, mainly material/matter (e.g. silicon, lithium, copper etc.) and land, and they can cause pollution as well. Solar and wind energy generation is land-intensive and in conflict with other land-uses, especially for food production and for forests or grassland as CO2-sinks. Hence, electricity generation, also from thermal renewable energy, is finite, even more with expected population increase. Only immaterial GDP may grow infinitely, but this is a rare species, or more energy saving can help. Structural change within the limits of the electricity budget remains possible which can impact output temporarily to some extent. Dreaming of large-scale energy imports from land-intensive countries disregards population growth in the South and the respective land-needs. If geopolitical land-conflicts between North and South are to be avoided renewable

[10] Some de-growth analyses circumvent the problem of a missing investment function by assuming falling consumption to which investments adjusts mechanically, as if it were demanded by a central planning authority. This would yield stable de-growth pathways, but underway reality of capitalism got lost.

energy trade has to be limited. Growth could return once population growth becomes negative after the global demographic transition. What remains is the fundamental certainty about the finiteness of the earth, be it land, materials or fossil energy. It will continue to haunt mankind. However, in this situation not zero-growth or a certain rate of de-growth is the target, rather a result of the guard-rails on land-use, emissions or other constraints, on the local, regional, national and global level.

If this outlook is foreshadowed, it might influence growth expectations already in the transition period and may either dampen expectations of excessive growth of electricity production and respective land-use, in line with dampened growth expectations, or spur competition among companies and countries to gain prerogatives.

The post-transitional quasi-zero-growth, in GDP terms, implies, as explained before, the decline of capitalism in the standard definition. Market economies without capital accumulation might survive, if the conditions mentioned above apply, though probably with strong state interventions. Those who dislike this and cling to global competition in zero sum games, risk huge collateral damages for all, especially for the generations to come.

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