1 Introduction

Climate change is one of the most pressing issues of our time. The science is clear: human activities also exacerbate the distributional implications of decarbonisation that will arise regardless (see for example Markkanen and Anger-Kraavi, 2019).

Yet, the sharp contrast in the theoretical positions of scholars is a way to conceptualise the magnit of the challenge. Striving for green growth is an imperative, but no one can be certain that such a path is possible. What is certain is that it cannot happen without some key prerequisites. It will require massive investment in existing green technologies and in the advancement of new breakthrough technologies, including for negative emissions. It will also require changed behaviour from everyone, and our economies will have to be adapted to deal with the consequences of climate change that can no longer be avoided.

The paper is structured as follows. Section 2 presents the numbers that make clear how significant the problem of decoupling is. Section 3 reviews the literature on degrowth and explains why degrowth proposals are not viable. Section 4 summarises the literature on green growth. Section 5 discusses essential steps for the realisation of green growth. Section 6 concludes with recommendations for policymakers.

2 The challenge of decoupling: the hard numbers

Pursuing deep decarbonisation will be challenging. Annual global GHG emissions keep rising and show no sign of peaking. In 2019, they were 62 percent higher than in 1990, the year of the first Intergovernmental Panel on Climate Change report, and 4 percent higher than in 2015 when the Paris Agreement was signed (Friedlingstein et al, 2020). Even unprecedented circumstances such as the massive restrictions introduced to contain COVID-19 led only to a 6 percent drop in emissions in 2020, from which a quick rebound to pre-pandemic levels promptly followed (IEA, 2021a).

Historically, economic growth … by which we mean real GDP growth … has long been associate increasing GHG emissions. Empirically, the causal chain is straightforward: higher levels of economic activity tend to go hand in hand with additional energy use and consumption of natural resources. Fossil fuels still account for 80 percent of the global energy mix (IEA, 2020), and so energy consumption is closely related to GHG emissions and hence to climate forcing. Expansion of industrial processes, livestock rearing and other agriculture adds to emissions, while deforestation reduces carbon sinks.

A far-reaching transformation of the global economy is needed to reduce emissions. As 73 percent of global GHG emissions come from energy production (mostly as CO_2), most reductions will need to happen in that area.[2] An interesting way to look at this is by formulating the problem as a simple identity, as done by Kaya and Yokobori (1998) on the basis of Holdren and Ehrlich (1974):

$$GHG\ emissions = population \times \frac{GDP}{population} \times \frac{energy\ demand}{GDP} \times \frac{GHG\ emissions}{energy\ demand}$$

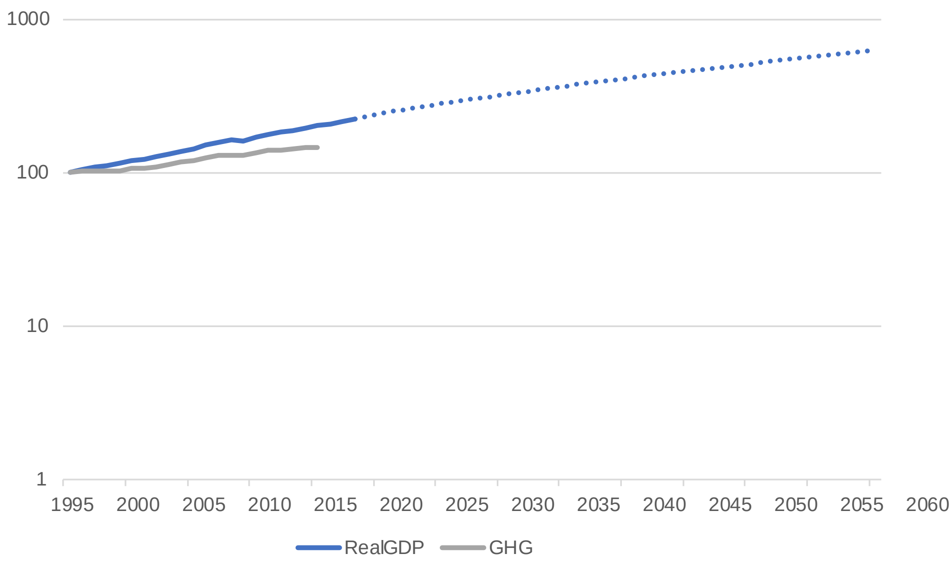
This identity permits GHG emissions (from energy production) to be decomposed into a product of the world's population size, GDP per capita, the energy intensity of GDP and the GHG emissions intensity of energy production.[3]

Limiting population growth is one way to limit GHG emissions, but the debate on this topic goes far beyond the scope of our paper. We instead consider population growth as a given, and base analysis on OECD demographic forecasts. Cuts in emissions would therefore need to happen by lowering some or all of the other factors. Since lowering the second factor (GDP per capita) implies compromising economic and social welfare, the core question is whether the third and fourth factors (energy and emissions intensity) can decline at a sufficient speed to allow the first and the second to remain on their current paths. This would imply an absolute decoupling of economic growth and GHG emissions (ie a situation in which GHG emissions go down while real GDP continues to grow, see Figure 1) through a 'dematerialisation' of the economy (eg through a shift from manufacturing to service altered consumption behaviour, more efficient technology) and the decarbonisation of the energy sector.

[2] The remaining emissions arise from agriculture (11.2 percent), land use (7.2 percent), industrial processes (5.2 perc and waste (3.2 percent) (see https://www.climatewatchdata.org/ghg-emissions). While this paper focusses mostly on GHG emissions from energy, the more difficult part of emissions reduction and sustainability in general may in fact be making the necessary changes in how we use natural resources to feed and dress ourselves. More on this in section 5.

[3] Energy production is what causes emissions, but the variable that must be impacted by policy is energy demand. We assume energy production is equal to demand (see IEA data [illegible]

Figure 1: Global real GDP (2010 prices, PPP) and total GHG emissions

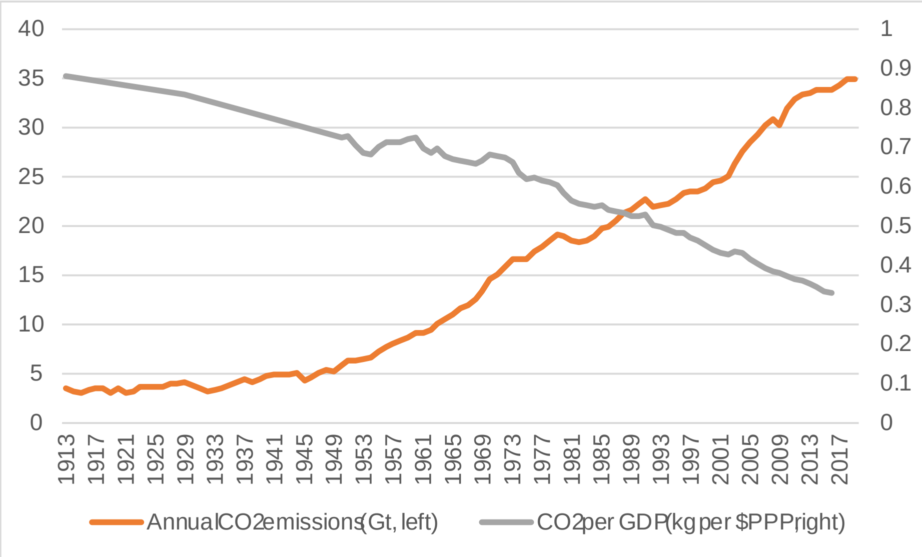


Source: Bruegel, based on OECD, Economic Outlook No 103 Long-term baseline projections, accessed in July 2021 and on UNEP, World Environment Situation Room (https://wesr.unep.org/downloader), accessed in July 2021. Note: 1995 = 100. Logarithmic scale. Full lines are historical data, dots are OECD projections, dashes are a stylised representation of absolute decoupling.

Globally, there is no sign of absolute decoupling, but only of relative decoupling (ie a situation in wh total GHG emissions grow less than proportionally to real GDP). Explained in terms of the Kaya identity, while energy related GHG emissions per unit of GDP are falling (the third and fourth factors combined), the fall is slower than the increase in real GDP (the first and second factors) so that ov emissions continue to rise. Figure 2 shows that in the last 100 years, annual CO_2 emissions from energy production have risen tenfold[4], even though emissions per unit of GDP have been slashed by almost two thirds (1.8 percent per year on average since 1990). This is simply because the global economy has grown at a much faster pace (2.8 percent per year on average since 1990).

[4] From here on we switch from showing data on total GHG emissions to data on CO_2 emissions for reasons of data availability and comparability to theoretical emission pathways. Since we focus on emissions mitigation in the energy sector, this is not an oversimplification: CO_2 represented 91 percent of global GHG emissions from energy in 2018 (CH_4 8.6 percent and N_2O 0.8 percent), and the energy sector accounts for 93 percent of global CO_2 emissions (industry: 4.1 percent and LULUCF: 3.3 percent) (see https://www.climatewatchdata.org/ghg-emissions). LULUCF = land use, land-use change and forestry.

Figure 2: Global annual CO_2 emissions from burning of fossil fuels for energy production (in gigatonnes) and CO_2 emissions per unit of GDP (in kg per $PPP)



Source: Our World in Data (OWID) CO_2 Data Explorer (based on Global Carbon Project; BP; Maddison; UNWPP), accessed in July 2021; see https://ourworldindata.org/co2-emissions

Thus, progress on decoupling GDP growth from CO_2 emissions has been achieved, but the continued expansion of the global economy has proven too fast to stop annual emissions from increasing, let alone to allow them to decrease, as is clear from Figure 2. A rough calculation (disregard interactions between the factors of the Kaya identity) makes clear how far the world is still falling short:

- Gross emissions of CO_2 stood at around 35 billion Gt in 2018 (Our World in Data, OWID; https://ourworldindata.org/co2-emissions). This needs to decrease to approximately 5 Gt in 2050 according to a technologically conservative emissions pathway[5] of the IPCC (2018), or by 86 percent.
- The global population is projected to increase from 7.63 billion in 2018 to 9.77 billion people in 2050 (x1.28), and global real GDP per capita (2010 prices) is projected to increase from $19,896 to $41,099 or by 107 percent (OECD).
- CO_2 emissions per unit of GDP therefore have to decline by around 95 percent or approximately 9 percent per year on average from 2019 until 2050. Between 1990 and 2016, the world only

[5] Loosely based on the LED/P1 pathway of the IPCC (2018), which uses neither carbon capture and storage technology (CCS) nor bioenergy with CCS (BECCS), technologies that are currently under development and that degrowth scholars deem unfit for climate change mitigation.

achieved an average so-called •decoupling rate• of 1.8 percent per year (based on OWID)[6]. Put differently, the average speed of decoupling during the next three decades will have to be almost five times greater. The later this acceleration happens, the greater it will have to be.

Decoupling trends are not even fast enough in developed economies. Since 1990 the European Union•s (EU) gross CO_2 emissions have decreased by 25 percent (OWID), while real GDP grew by 62 percent (European Commission, 2020a). CO_2 emissions in the United States also started to decline more recently. This suggests that absolute decoupling is possible. But it is happening too slowly to match the globally required decoupli

Such pessimistic views about our planet•s capacity to sustain economic growth are not new. They have been around in some form at least since the Ea e Pce f Pa by Thomas Malthus (1789). He postulated that mass famine and economic collapse were inevitable unless birth rates decreased, based on the belief that population growth is exponential and growth of food production merely linear. This argument was echoed throughout the twentieth century in environmentally inspired works by, for example, Osborn (1948), Vogt (1948) and, most notably, in The P B by Paul Ehrlich (1968). Meadows et al (1972) predicted in The L G (hereafter LTG) that global population and economic activity would peak in the twenty-first century, and advocated an economic and demographic e ie” to avoid an uncontrolled collapse when humanity•s need for resources finally exceeds the earth•s capacity.

These authors all proved to be too pessimistic (at least so far) because they failed to predict the significant advances in agricultural yields, technological innovation and substitution, and declines in population growth rates. Advances in resource efficiency have often been driven by market forces, such as for oil in the 1970s, when scarcity drove up prices, creating incentives for innovation. However, technological progress is highly unpredictable, and since the atmosphere as a deposit CO_2 is a rival but non-excludable good, purely market-driven innovation and substitution will not sol the problem of climate change (Ekins et al, 2010).

Like LTG, modern degrowth theories subscribe to the idea that humanity must achieve a lower economic •steady state• to avoid environmental catastrophe. The term •degrowth• was probably first used in the writings of French philosopher André Gorz in 1972, and in the work of econom Georgescu-Roegen (1971, 1979), who wrote that economic activity in the long run is limited to a level supported by solar flows due to the laws of thermodynamics. The term was popularised in the 1990s and 2000s by Serge Latouche (for example Latouche, 2009) who criticised economic development as a goal. In the early 2000s •degrowth• was used as a slogan by social and environmental activists in France, Italy and Spain. Finally, it emerged as an international research area in 2008 at the first Degrowth Conference in Paris (Demaria et al, 2013; Kallis et al, 2018), with many publications being produced, particularly in the first half of the 2010s, in the context of the global financial crisis and the sovereign debt crisis in Europe. Authors including

There is no exact definition of what •degrowth• stands for. Authors are not always clear on exactly what should •degrow•. There are at least five different interpretations: degrowth of GDP, consumption, worktime, the economy•s physical size, or •radical• degrowth, referring to a wholesale transformation of the economic system (van den Bergh, 2011). It is perhaps better to say that degrowth covers all these interpretations. Material and energy consumption and the economy•s physical size need to degrow, out of a concern for resource depletion and more concretely climate change. Worktime degrowth is one tool to do so, GDP degrowth is an inevitable consequence (not an aim), and radical degrowth a necessary condition to make a post-growth economy socially sustainable (Kallis, 2011).

In terms of GDP and GHG emissions, degrowth scholars do not see a credible scenario in which th common proposal is to limit the supply of production factors, most notably labour. Reductions in working hours are seen as a way to reduce consumption while increasing social welfare through more free time and achieving high levels of employment. The latter must also be supported by shifting employment towards labour-intensive sectors and steering innovation to increase resource productivity rather than labour productivity, using green taxes and •cap-and-share• schemes (Kallis, 2011; Kallis et al., 2018). Another element is to reduce aggregate investment by firms to net zero, which does not exclude that some (clean) sectors grow at the expense of other (dirty) sectors (Kallis et al., 2018).

Other ideas found in the literature are the re-localisation of economies to shorten the distance between consumers and producers, and encouragement of the craft economy (Paech, 2012), as well as new forms of (regional) money and limitations to property rights (Kallis et al., 2012; van Griethuysen, 2012). Some advocate for zero interest rates to avoid the growth imperative created by having to pay back interest (Binswanger, 2013), caps on savings to reduce wealth inequality and doing away with the logic of accumulation by firms and owners of capital. The aim is to arrive at a steady state in which the whole economy is consumed, which would end growth (Loehr, 2012).

Importantly, many of the proposed policies are considered by authors themselves to be incompatible with capitalism and unlikely to be implemented in liberal representative democracies. Kallis (2018) therefore argued that in the absence of democratic degrowth policies a period of involuntary economic stagnation caused by climate change might usher in an authoritarian version of capitalism, unless more democratic alternatives are put forward.

Finally, it should be noted that degrowth proponents devote relatively little attention to limiting population growth, which would theoretically offer another … though contentious … way to reconcile GDP per capita growth and emission reductions. Where it is discussed, most authors view it as undesirable, especially when non-voluntary, and point out that the large and growing populations of

4 Green growth

The calculations in section 2 illustrate the scale of the challenge. However, it is also important to note that the low decoupling rate up to now has occurred in a context in which there hasn't been a significant climate effort globally, and developed economies have put in place only modest policies. This pattern need not continue, and there are signs that it might not.

The EU has already managed to cut its territorial emissions of CO_2. This is of course partly due to lower population and GDP per capita growth than the global average. But data also shows that the decoupling

2

Figure 3: Levelised cost of energy (LCOE) from selected fossil fuels and renewable energy sources, in USD/MWh

Source: Lazard (2020).

Already in the earlier literature rejecting the growth pessimism, the central role of technology was highlighted. Stiglitz (1974) and Kamien and Schwartz (1978) did not yet address GHG emissions, but

Nations• Sustainable Development Goals[9], and to varying degrees different Green (New) Deal proposals (eg European Commission, 2019; US House of Representatives, 2019).

No single definition has been developed of what is meant by •green growth•. For example, the World Bank (2012), OECD (2011) and UNEP (2011) each define green objectives differently (Hickel and Kallis, 2020). Jacobs (2012) notes that green GDP growth is understood as either: (1) higher growth than in a scenario without strong environmental or climate policies, both in the short and long run (dubbed the •strong• version of green growth), or (2) lower in the short run and higher in the long run (the •standard• version)[10].

Whatever the exact interpretation of green growth, publications from international organisations or governments predict both environmental benefits in the form of avoided climate damages and economic benefits resulting from increased investment and innovation.[11] This •double dividend• forms the heart of the green-growth argument. The green-growth narrative rests on four pillars: (1) subsidies for innovation and investments in renewable energy and energy efficiency to boost GDP; (2) carbon pricing to further stimulate efficiency gains and renewables, to avoid rebound effects, combined with recycling of tax revenues to cut corporate or labour taxes and boost employment; (3) assumptions about innovation on negative emission technologies to accelerate the decoupling process; and (4) compensation schemes for the poorest households, displaced workers or disadvantaged regions to make the transition politically feasible (see for example Table 2). Inclusion of such social elements puts current proposals beyond earlier incarnations of Green New Deals (Mastini et al, 2021). In its most extreme form, green growth is believed to come as a result of free markets and does not even require public intervention other than carbon pricing (eg Guerrieri (2019) refer to this as “[illegible]”).

---

[9] The SDGs indeed also include •Decent Work and Economic Growth• as SDG8.

[10] Adding to the confusion is lack of clarity about the baseline against which growth is usually compared: is it a trajectory based on historical average growth rates or a no-action scenario that includes serious damage from climate change in the long run? This is not trivial, as in comparison to an economy wrecked by runaway climate change, an economy that avoids global warming by growing more slowly or even by shrinking could be on a higher growth path, but this is generally not a scenario considered as •green growth•.

[11] The environmental benefits are sometimes augmented by more short-term co-benefits, mostly through improved health; see Karlsson et al (2020) for an overview.

Table 2: Different green growth scenarios, showing targeted emission reductions, estimated GDP impact, key policies, and adversely affected groups (if no compensation)

	IMF (2020)	European Commission (2020b)[12]	IEA (2021b)
Emission reductions	Reduce gross global emissions by 80% by 2050	Reduce net EU emissions by 55% by 2030	Reduce global net CO2 emissions to zero by 2050
GDP impact	Standard version: baseline GDP +0.7% first 15 years, -1% in 2050, +13% in 2100	Standard version: baseline GDP -0.27% / +0.50% by 2030	Strong version: baseline GDP +4% in 2030
Key policies	x green investment push x carbon pricing x compensatory transfers supportive macro policies	x green investment push x carbon pricing x tax recycling	x green investment push x carbon pricing
Adversely affected groups	x Low-income households, due to electricity prices and job status x Fossil fuel exporters	x Fossil fuel industry x Low-income households	x Fossil fuel exporters x Fossil fuel industry

Source: Bruegel.

Overall, however, the empirical evidence for a double dividend looks mixed. In fact, some of the reports by official institutions state that a double dividend can be achieved only if very specific assumptions are made, while in many scenarios, strong climate action could at least in the short-term lower GDP growth.

[12] Includes JRC-GEM-E3, E3ME and E-QUEST model estimates.

5 Techno-optimism: important caveats

The numbers we have given show that the world needs to decouple gross GHG emissions and GDP growth much faster than currently. In the following, we set out the key actions necessary to achieve such a faster decoupling[13].

5.1 Need for massive investment in deployment of existing green technologies

To decouple GHG emissions and GDP growth, a huge expansion in green investment and a big shift in investment are needed. For instance, the IEA's (2021b) net-zero pathway estimates that global energy capital investments must increase from a current yearly average of about $2 trillion to $5 trillion (2019 prices) by 2030, after which they must stay at almost the same level until 2050. As a fraction of glo GDP, this would be an increase from 2.5 percent today to 4.5 percent in 2030, followed by a gradual decline back to 2.5 percent. Encouragingly, most of the technologies to be invested in up to 2030 (for 85 percent of emission reductions; see IEA, 2021b) are readily available. Beyond 2030, that will be much less the case: only 54 percent of emission reductions will be accomplished with curre technologies. Most of the investment up to 2050 (about 65 percent) would be directed to generating low-carbon electricity, upgrading the electricity system for distribution and storage and electrifying new sectors of the economy (CO2/energy demand), while a smaller though still significant share (about 15 percent) would be spent on efficiency improvements (energy demand/real GDP).

Governments will have to foot part of the bill, especially large infrastructure projects or technologies still under development (IEA, 2021b). But the private sector will need to cover most of the investments. It is therefore important that governments use policies to create incentives and facilitate investments, for example through carbon pricing, green financial regulations and supervisory practises, or cooperation with the private sector through public financial institutions such as the European Investment Bank. Clear and credible policy commitments also help by reducing the uncertainty that can keep firms from investing (Dechezleprêtre, 2021).

5.2 Need for breakthrough green technologies for decarbonisation

Most emission reduction scenarios that predict continued economic growth rely to varying degrees on the use of technologies that are not yet available. This is frequently used by degrowth proponents as an argument to question the feasibility of green growth. The IEA net-zero pathway (2021b), for

[13] Because of the nature of renewable energy, global supply chains, and the consequences of climate change, as well as the benefits to be had from cooperation in R&D, each of these points should be addressed with international cooperation

instance, relies to a great extent on future innovation: 15 percent of the emissions reductions by 2030 and 46 percent of the reductions between 2030 and 2050 are to be achieved with technologies that are currently in a demonstration or prototype phase, such as CCS, green hydrogen and advanced batteries.

The breakthroughs achieved in the current decade will therefore be crucial. Unfortunately, none of the technologies needed beyond 2030 are currently on track to being deployed in time (IEA, 2021c), as the road from concept to commercialisation is typically long and winding. To accelerate the development of these innovative technologies, governments and the private sector both need to substantially increase their research and innovation funding. Fostering green innovation and bringing green technologies from the laboratory to the market requires government action, for example via pricing of emissions. Public-private partnerships, adequate risk-taking by public institutions and green industrial policy can help deliver breakthrough innovation (Tagliapietra and Veugelers, 2020). But, of course, there cannot be a guarantee that such breakthrough technologies will materialise in time.

5.3 Need to foster behavioural change

In theory, emissions from energy production could be sufficiently reduced solely on the back of

Figure 4: Impact of behavioural change in the IEA net-zero roadmap, emission reductions and increases from now to 2050 (megatonnes of CO_2)

Source: International Energy Agency (2021b).

Behavioural change can also reduce the cost of the green transition. To appreciate this point, it is useful to compare the EU investment requirements to reach net zero by 2050 estimated by t European Commission under two different scenarios: one relying only on technology (1.5 TECH), and one relying on both technology and behavioural changes (1.5 LIFE). Between 2031 and 2050, the 1.5

We have not made much progress in decoupling GHG emission from food production (1.0 percent per year since 1990, according to FAO data). As Turner (2020) put it, the technology •cow• has indeed barely changed over the last millennia. GHG emissions per kilo of meat from cattle have declined mere 0.4 percent per year on average since 1990. They account for 37 percent for all emissions from food production documented by the FAO[15] (FAOSTAT, 2021). A change in diet and the way we use land for producing other goods might thus become necessary.

Bearing this in mind, it is important to consider the •red flag• warnings of rebound effects. If policies to reduce emissions through investments in renewables and efficiency gains achieve positive income effects or too optimistic perceptions, a narrow focus on certain sectors could leave room for harr effects from increased emissions elsewhere. This could offset at least part of the progress made emission reductions from energy[16]

5.4 Need to develop and scale-up negative emission technologies

All IPCC emission pathways, including the one on which we based our calculations in sections 2 and 3, consider net CO_2 emissions, with reductions from agriculture, forests and other land use. Reforestation, afforestation, habitat- and soil management can be used to remove CO_2 from the atmosphere, provided that increased efforts are made in these areas as well. Thus gross emissions can remain small but positive in a net-zero situation.

Unlike the conservative pathway we used, most of the IPCC pathways (IPCC, 2018) also rely significantly on man-made negative emission technologies. They allow for greater remaining CO_2 emissions from activities that are hard to decarbonise when reaching climate neutrality by mid-century and beyond, as these are offset by more carbon removal. This in turn means that the high required decoupling rate of around 9 percent becomes somewhat lower, which would make a difference in the feasibility of net-zero by mid-century.

This is controversial among climate scientists, however. Negative emission technologies are curre under development or in early small-scale implementation and are not on track to being ready in t (IEA, 2021c). Furthermore, many scientists are also sceptical about the feasibility and viability of certain technologies and are even worried that they create numerous other serious environmental problems because of potentially high input requirements.

[15] See FAOSTAT, Agri-Environmental Indicators, http://www.fao.org/faostat/en/#data, accessed on 20 July 2021.
[16] In the absence of a limit or prices on emissions, there can also be rebound effects within the energy sector, for example when people start using more energy because it is becoming cheaper or greener. This means increases in energy demand/real GDP offset decreases in CO2/energy demand.

Governments should encourage the development of both natural and technological solutions but should be keenly aware that negative emission technologies cannot be a substitute for actual, immediate emission abatement.

5.5 Need to adapt our economies to unavoidable climate change

Global efforts to reduce GHG emissions are aimed at limiting global warming to 1.5°C, thus minimising dangerous climate change. Unfortunately, with average temperatures already more than 1.0°C above pre-industrial levels (IPCC, 2018) climate change is

6 Conclusions

In order to avoid global warming in excess of 1.5°C above pre-industrial levels, global GHG emissions must be rapidly reduced. Doing this without losses in economic prosperity will not be easy: so far, decoupling GHG emissions from GDP growth has been slow or absent. This is the justification for degrowth scholars to propose a radical overhaul of our economic system. Yet this approach seems unrealistic. Asking for lower growth, let alone negative growth, would mean that large parts of the w could not develop, or only at the expense of even harsher degrowth in developed countries. L income countries will obviously not follow this advice and the notion of redistributing income from rich to poor countries is also unrealistic.

The real question therefore becomes whether decarbonisation efforts can be accelerated. While global emissions have not declined, GHG emissions from developed economies such as the EU have, de continued economic growth. The data also shows that the speed of decoupling of emissions and growth has accelerated in the world. The efforts to reduce the carbon intensity of energy in many economies have contributed to a steep decline in the prices of renewable energy technology, which has improved the economic case for rapid decarbonisation worldwide. Belief that further innovation and investment will enable the world to successfully reach climate neutrality by 2050 without reducing welfare underlies the green-growth narr

References

Acemoglu, D., P. Aghion, L. Bursztyn and D. Hemous (2012) •The environment and directed technical change•, Aeca Ecc Ree 102(1):131-166, available at http://dx.doi=10.1257/aer.102.1.131

Aghion, P., A. Dechezlepretre, D. Hemous, R. Martin and J. Van Reenen (2016) •Carbon taxes, path dependency and directed technical change: evidence from the auto industry•, Jal f Pcal Ec, 124(1):1-51, available at https://doi.org/10.1086/684581

Antal, M. and J. van den Bergh (2016) •Green Growth and climate change: conceptual and empirical considerations•, Clae Plc 16(2):165-177, available at https://doi.org/10.1080/14693062.2014.992003

Binswanger, H. (2013) Te G Sal, Berlin: Springer

Cosme, I., R. Santos and D. O'Neill (2017) •Assessing the degrowth discourse: a review and analysis of academic degrowth policy proposals•, Jal f Clea Pdc, 149: 321-334, available at https://doi.org/10.1016/j.jclepro.2017.02.016

Demaria, F., F. Schneider, F. Sekulova and J. Martinez-Alier (2013) •What is degrowth? From an activist slogan to a social movement•, Ev al Vale, 22(2): 191-215, available at https://doi.org/10.3197/096327113X13581561725194

Dechezleprêtre, A., T. Kruse and C. Berestycki (2021) •Measuring and Assessing the Effect of Environmental Policy Uncertainty•, Economics Department Working Paper, Organisation for Economic Cooperation and Development, forthcoming

Eastin, J., R. Grundman and A. Prakash (2011) 'The two limits debates: Limits to growth and climate change•, Fe 43(1): 16-26, available at https://doi.org/10.1016/j.futures.2010.03.001

Ehrlich, P. (1968) Te Pa Bb, Sierra Club/Ballantine Books

Erbach, G. and G. Victoria (2021) •Carbon dioxide removal. Nature-based and technological solutions•, Bef, European Parliamentary Research Service, available at https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BRI(2021)689336

European Commission (2018) I-depth aa f e C Cca COM(2018) 773 'A Cea Pae f A' , available at https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

European Commission (2019) •The European Green Deal•, COM(2019) 640 final, available at https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN

European Commission (2020a) AMECO Oe , available at https://dashboard.tech.ec.europa.eu/qs_digit_dashboard_mt/public/sense/app/667e9fba-eea7-4d17-abf0-ef20f6994336/sheet/f38b3b42-402c-44a8-9264-238421d2/state/analysis/

European Commission (2020b) •Impact assessment accompanying the document •Stepping up Europe•s 2030 climate ambition: Investing in a climate-neutral future for the benefit of our peopleŽ, SWD(2020) 176 final, available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0176

European Commission (2020c) Cae cae ac a d adaa Ee , JRC PESETA IV final report, available at https://ec.europa.eu/jrc/en/peseta-iv

Friedlingstein, P., M. O'Sullivan, M.W. Jones, R.M. Andrew, J. Hauck, A. Olsen ... S. Zaehle (2020) •Global Carbon Budget 2020•, Ea Se Scece Daa 12(4): 3269-3340, available at https://doi.org/10.5194/essd-12-3269-2020

Georgescu-Roegen, N. (1971) Te E a ad e Ecc Pce , Cambridge: Harvard University Press

Georgescu-Roegen, N. (1979) Demain la décroissance : entropie-écologie-économie, Lausanne: Pierre-Marcel Favre

Gorz, A. (1972) •Proceedings from a public debate•, Le Nouvel Observateur, 19 June

Gueret, A., A. Saussay and X. Timbeau (2019) •On the economics of a Green (New) Deal•, presentation to OFCE Paris meeting, 16 Sept

Haut Conseil pour le Climat (2020) Maîtriser l'empreinte carbone de la France , available at https://www.hautconseilclimat.fr/wp-content/uploads/2020/10/hcc_rapport_maitriser-lempreinte-carbone-de-la-france-1.pdf

Hickel, J. and G. Kallis (2020) •Is Green Growth Possible?• Ne Pca Ec 25(4):469-486, available at https://doi.org/10.1080/13563467.2019.1598964

Hickel, J. (2020) e: de ae e d, Cornerstone

Holdren, J. and P. Ehrlich (1974) •Human Population and the Global Environment: Population growth, rising per capita material consumption, and disruptive technologies have made civilization a global ecological force•, Aeca Sce 62(3):282-292, available at https://www.jstor.org/stable/27844882

IEA (2020a) Wd Ee O 2020, International Energy Agency, available at https://www.iea.org/reports/world-energy-outlook-2020

IEA (2020b) CO2 E f Fe Cb Sa c. Idca f CO2 e (Ed 2020), International Energy Agency, available at https://doi.org/10.1787/co2-data-en

IEA (2021a) •After steep drop in early 2020, global carbon dioxide emissions have rebounded strongly•, press release, 2 March, International Energy Agency, available at https://www.iea.org/news/after-steep-drop-in-early-2020-global-carbon-dioxide-emissions-have-rebounded-strongly

IEA (2021b) Ne Ze b 2050. A ada f e ba ee ec, International Energy Agency, available at https://www.iea.org/reports/net-zero-by-2050

IEA (2021c) Tac Cea Ee Pe, International Energy Agency, available at https://www.iea.org/topics/tracking-clean-energy-progress

IEA (2021d) Wd Ee lee 2021, International Energy Agency, available at https://www.iea.org/reports/world-energy-investment-2021

IMF (2020) •Mitigating Climate Change•, chapter 3 in Wd Ecc O : a ad dffc ae, International Monetary Fund, available at https://www.imf.org/en/Publications/WEO/Issues/2020/09/30/world-economic-outlook-october-2020

IPCC (2018) Gba Wa f 1.5 C, Special Report, Intergovernmental Panel on Climate Change, available at https://www.ipcc.ch/sr15/

Jackson, T. (2009) P G: Ecc f a Fe Pae, London: Earthscan

Jacobs, M. (2012) •Green growth: economic theory and political discourse•, W Pae No. 92, Grantham Research Institute on Climate Change and the Environment, available at https://www.lse.ac.uk/granthaminstitute/publication/green-growth-economic-theory-and-political-discourse-working-paper-92/

Kallis, G., C. Kerschner and J. Martinez-Alier (2012) •The economics of degrowth•, Ec Ec, 84: 172-180, available at https://doi.org/10.1016/j.ecolecon.2012.08.017

Kallis, G., V. Kostakis, S. Lange, B. Muraca, S. Paulson and M. Schmelzer (2018) •Research On Degrowth•, Aa Ree f Ee ad Rece 43: 291-316, available at https://doi.org/10.1146/annurev-environ-102017-025941

Kallis, G. (2011) •In Defence of Degrowth•, Ec Ec, 70(5): 873-880, available at https://doi.org/10.1016/j.ecolecon.2010.12.007

Kamien, M. and N. Schwartz (1978) •Optimal exhaustible resource depletion with endogenous technical change•, Ree f Ecc Sde, -nc0.0i5.g79-196, available at https://www.jstor.org/stable/2297093?seq=1

Karlsson, M., E. Alfredsson and N. Westling (2020) •Climate policy co-benefits: a review•, Ca Pc, 20(30i5.292-316, available at https://doi.org/10.1080/14693062.2020.1724070

Kaya, Y. and K. Yokoburi (1998) E, E ad ec : aee f aab, Tokyo: United Nations University Press

Keysser, L. and M. Lenzen (2021) •1.5°C degrowth scenarios suggest the need for new mitigation pathways•, Nae Cca 12(2676) , available at https://doi.org/10.1038/s41467-021-22884-9

Latouche, S. (2009) Faee G, Cambridge: Polity

Lazard (2020) Laad'eeed c f e e aa Ve 14.0, available at https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/

Leonard, M., J. Pisani-Ferry, J. Shapiro, S. Tagliapietra and G. Wolff (2021

Loehr, D. (2012) •The euthanasia of the rentier„a way toward a steady-state economy?• *Ecc* 84: 232…239, available at https://doi.org/10.1016/j.ecolecon.2011.11.006

Malthus, T. (1798) *A Ea e Pce f Pa*, London: J. Johnson

Markkanen, S. and A. Anger-Kraavi (2019) •Social impacts of climate change mitigation policies and their implications for inequality•, *Cae Pc* 19(7): 827-844, available at https://doi.org/10.1080/14693062.2019.1596873

Mastini, R., G. Kallis and J. Hickel (2021) •A Green New Deal without growth?• *Ecc* 179: 1-9, available at https://doi.org/10.1016/j.ecolecon.2020.106832

Meadows, D., D. Meadows, J. Randers and W. Behrens (1972) *Te*, 5th printing, New York: Universe Books

Osborn, F. (1948) *Ped ae*, New York: Little, Brown and Company

OECD (2009) *Dcaa Gee G*, Organisation for Economic Cooperation and Development, available at https://www.oecd.org/env/44077822.pdf

OECD (2011) *Tad ee*, Organisation for Economic Cooperation and Development, available at https://www.oecd.org/env/towards-green-growth-9789264111318-en.htm

OECD (2018) •Economic Outlook No 103 … Long term baseline projections•, Organisation for Economic Cooperation and Development, available at https://www.oecd-ilibrary.org/economics/data/oecd-economic-outlook-statistics-and-projections/long-term-baseline-projections-no-103_68465614-en

OECD (2021) *Pa ee*, Organisation for Economic Cooperation and Development, available at https://data.oecd.org/energy/primary-energy-supply.htm

Paech, N. (2012) *Befe Üef: af de We de Pacee*, Munich: Oekom Verlag

Peters, G.P., J.C. Minx, C.L. Weber and O. Edenhofer (2011) •Growth in emission transfers via international trade from 1990 to 2008•, *Pceed f e Na a Acade f Scece* 108: 8903-8908, available at http://www.pnas.org/content/108/21/8903.abstract

Raworth, K. (2017) *Dc: ee a e a 21 -ce ec*, London: Random House

Stern, N. (2007) Te Se Ree: e ecc f cae cae, Cambridge University Press

Stiglitz, J. (1974) •Growth with exhaustible natural resources: efficient and optimal growth paths•, Ree f Ecc Sde, 41: 123-137, available at https://www.jstor.org/stable/2296377?seq=1

Tagliapietra, S. and Veugelers R. (2020) A ee da c f Ee, Blueprint 31, Bruegel, available at https://www.bruegel.org/2020/12/a-green-industrial-policy-for-europe/

Turner, A. (2020) •Techno-optimism, behaviour change and planetary boundaries•, Keele World Affairs Lectures on Sustainability, available at http://www.kwaku.org.uk/Documents/Techno%20optimism%20behaviour%20change%20and%20planetary%20boundaries%20Nov%202020.pdf

UNEP (2011) d a ee ec. Paa Saabe Deee ad Pe Eadca, United Nations Environment Programme, available at https://www.unep.org/resources/report/towards-green-economy-pathways-sustainable-development-and-poverty-eradication-10

UNEP (2020a) E Ga Re 2020, United Nations Environment Programme, available at https://www.unep.org/emissions-gap-report-2020

UNEP (2020b) Adaa Ga e 2020, United Nations Environment Programme, available at https://www.unep.org/resources/adaptation-gap-report-2020

UNFCCC (2015) Ldee.C.13/1 300. 24.51 T.66e-deee-

Vogt, W. (1948) Rad Sal , New York: William Sloane Associates

Weitzman, M. (1999) •Pricing the limits to growth from minerals depletion•,

bruegel

Bruegel, Rue de la Charité 33, B-1210 Brussels
(+32) 2 227 4210
info@bruegel.org
www.bruegel.org