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Living Within Biophysical Limits green growth versus degrowth

Abstract

Since the early 1970s there has been vigorous debate over whether global economic growth can continue more or less indefinitely on a finite planet. Central to the most recent version of this debate are the claims and counterclaims of those advocating 'green growth' and those advocating 'degrowth'. This article outlines and briefly assesses the main areas of agreement and disagreement between these contending schools of thought. It is argued that humanity must live within real, non-negotiable biophysical constraints. Failure to make the required transformation of the global economy soon will ultimately undermine social progress. But what level and form of global economic activity is ultimately compatible with ecological sustainability remains uncertain.

Keyword green growth, degrowth, decoupling, decarbonisation, environmental sustainability

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Vigorous debate continues over the feasibility and desirability of unending global economic growth, even at modest annual rates (e.g., 2–3%). At stake is whether economic growth, as measured by an increase in gross domestic product (GDP), is compatible with – and perhaps even necessary for – environmental sustainability and intergenerational wellbeing. In short, is global GDP growth (and higher per capita incomes) counterproductive and thus 'uneconomic', in the sense that the overall long-term costs will outweigh, and perhaps even dwarf, the overall long-term benefits? Further, even if global GDP growth is technically possible for much of the 21st century, is it feasible indefinitely, and what bearing should this have on current policymaking? Can there be an unlimited global economy on a finite Earth? Can humanity continue to increase the value of the goods and services it produces independent of resource throughput and damaging environmental impacts?

Central to the current debate are the contrasting assumptions, assertions and policy prescriptions of the advocates, respectively, of 'green growth' and 'degrowth'. Those championing 'green growth' (also referred to as 'sustainable economic growth' and 'ecomodernism') include major international organisations, such as the International Energy Agency (2009, 2021), the OECD (2011), the United Nations

Environment Programme (UNEP, 2011a, 2011b, 2017) and the World Bank (2012), along with numerous leading economists and policy experts.[1] Many green-oriented policy packages have been advanced over the past decade or so, such as the 'global green new deal', the 'European green new deal' and the US version. Significantly, however, not all proponents of the 'green economy' support continued, let alone indefinite, GDP growth.

For their part, the advocates of 'degrowth' (sometimes referred to as 'anti-growth' or 'post-growth') comprise researchers from multiple disciplines within the social and biophysical sciences, including many ecological economists.[2] While the global debate continues to evolve and new evidence is constantly emerging, the main fault lines are now well established.

This article identifies and briefly assesses the key claims and counterclaims at the heart of this debate. It proceeds as follows. First, it clarifies the meaning of several important terms and concepts. Second, it places the current debate in the context of earlier debates about the relationship between economic growth and environmental limits. Third, it summarises the main areas of agreement and disagreement between the contending schools of thought. Finally, it offers a brief assessment.

Several caveats

Several caveats deserve mention. First, doing justice to the scope and significance of the topic is impossible in a short article. The relevant academic literature on green growth and degrowth and their many variants is already vast and continues to expand rapidly. Moreover, it traverses an extraordinary range of issues – philosophical, ethical, political, technological, biophysical, behavioural, social, cultural and economic. Some of these issues are highly technical and inherently complex. There is also much disputed empirical evidence and numerous uncertainties. Accordingly, this brief analysis is limited to the main contours of the debate. It does not address, therefore, the wider societal and ethical issues raised by the green growth/ degrowth debate, such as those relating to global governance, population limits, aid and development and intergenerational justice.

Second, several related schools of thought are ignored here. One of these is 'ungreen growth' or 'brown growth'; another is 'a-growth'. The former approach either rejects the need for the global economy to operate within biophysical limits or denies that such limits exist. Neither position is scientifically plausible. The latter approach involves being agnostic or neutral about GDP growth (see van den Bergh, 2009, 2011, 2017; van den Bergh and Kallis, 2012) and/or prioritising other policy goals (e.g., wellbeing, social welfare, etc.) (see, for instance, Jacob and Edenhofer, 2014). Such perspectives merit serious consideration. But while there are good reasons to deprioritise GDP as a performance measure, the suggestion that GDP growth is largely irrelevant or inconsequential from a policy perspective is less convincing. Politically, too, the proposition that governments should simply be indifferent to economic growth, and hence to changes in per capita incomes, is likely to be difficult to justify, not least in low-income countries.

> ... decoupling 'is reducing the amount of resources such as water or fossil fuels used to produce economic growth and delinking economic development from environmental deterioration'

Third, the relative merits of green growth and degrowth can be investigated at multiple scales (e.g., global, regional, national, sub-national) and over radically different time horizons (e.g., decades and centuries). Given the current serious ecological issues facing humanity at a planetary level – not least anthropogenic climate change, large-scale biodiversity loss, extensive pollution and rapid depletion of many non-renewable resources – the crucial analytical issues are global rather than local. In short, the fundamental question is whether continued (even modest) annual *global* GDP growth (both in aggregate and per capita) is a feasible and desirable policy objective over an extended time frame (e.g., the next 50–100 years) rather than, say, the next decade or two. Answering this question necessarily requires a global focus. Equally, the relevant timespan must be multi-decadal, not short term. What might be possible within individual countries (e.g., see Hatfield-Dodds et al., 2015) or over much shorter time horizons are separate issues and are not explored here.

Fourth, this analysis accepts the seriousness of the current global ecological challenges and hence the need for urgent and effective policy responses at the national and sub-national levels (e.g., see IPBES, 2019; IPCC, 2018, 2021; OECD, 2021). There is no suggestion, therefore, that the decisions of national policymakers, and especially those in the major economies (e.g., the US, China and the EU), are irrelevant to the green growth/degrowth debate. But it is beyond the scope of this analysis to consider national-level policy options, strategies and pathways, whether for major economies or much smaller ones such as Aotearoa New Zealand. That said, no country has fully embraced, let alone achieved, a genuinely sustainable pathway ecologically.

Defining key terms

Economic growth and gross domestic product (GDP)

Economic growth is typically measured by changes in GDP over a specified period (e.g., quarterly or annually). GDP is a monetary measure or indicator of economic value; it is not a measure of physical properties, such as natural resources or energy flows. It is generally defined as the market value of all the final goods and services produced in a country over a particular time frame. It can be expressed in various ways (e.g., as an aggregate or per capita measure), and changes can be measured in either real or nominal terms. Global GDP is simply the aggregate of the GDP of every nation (currently close to 200). In 2021 global GDP was approximately US$95 trillion. Significantly, the composition of GDP can, and does, change over time and it varies greatly between countries. For the purposes of this article, economic growth and GDP growth will be used interchangeably.

Green growth

The concept of green growth has various strands and definitions. In broad terms, it involves a commitment to continued GDP growth, both globally and nationally, on the grounds that growth, at least of certain kinds, is beneficial in net terms – socially, politically and environmentally. The crucial caveat, however, is that future growth must be consistent with clearly identified biophysical limits at multiple scales (e.g., global, national and local). Accordingly, advocates of green growth support a raft of fiscal and regulatory policies to enhance the efficient use of resources (both renewable and non-renewable) and minimise waste (i.e., embrace a more circular economy), improve societal resilience, and minimise environmental pressures. To quote from a major OECD report, *Towards Green Growth*:

> A green growth strategy is centred on mutually reinforcing aspects of economic and environmental policy. It takes into account the full value of natural capital as a factor of production and its role in growth. It focuses on cost-effective ways of attenuating environmental pressures to effect a transition towards new patterns of growth that will avoid crossing critical local, regional and global environmental thresholds … It is about fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. (OECD, 2011, pp.10, 18)

Degrowth

As with 'green growth', the concept of 'degrowth' comprises multiple strands and definitions (see Hagens, 2020; Hickel and Kallis, 2020; Hickel and Hallegatte, 2021; IPCC, 2022; Ward et al., 2016). Indeed, those associated with the degrowth camp differ markedly in their philosophical, ideological and policy preferences. Hence, some degrowth proponents (for example, Jason Hickel and Juila Steinberger) have more affinity with green growth advocates, at least on certain matters, than with their more radical associates (e.g., see Seibert and Rees, 2021).

Be that as it may, degrowth advocates are united in rejecting economic growth as a legitimate policy goal and oppose using GDP as an indicator of societal progress or prosperity. Instead, much broader policy goals and progress indicators are favoured (Jackson, 2009 ; see also Stiglitz et al., 2009). Nonetheless, many advocates endorse (at least temporary) additional GDP growth per capita in low-income countries, if not also in emerging economies, to reduce poverty and enhance human wellbeing. By contrast, continuing GDP growth in high-income (OECD) countries is rejected. There is no consensus, however, over whether average per capita incomes in high-income countries needs to fall, and, if so, by how much, over what specific time frame and by what means.

> … there has been mounting evidence that humanity is harming vital biophysical systems, living beyond Earth's means … and exceeding 'safe' planetary boundaries …

Second, degrowth advocates favour slowing and then reversing global resource consumption, commodity production and energy usage until they reach genuinely sustainable levels. This entails support for a raft of regenerative policies to reduce the aggregate use of natural resources (e.g., via comprehensive recycling, reusing, refurbishing, remaking, sharing, etc.), lower the physical throughput of the global economy, decrease overall energy consumption, and decarbonise global energy systems rapidly (i.e., within about three decades) to achieve net zero carbon dioxide (CO_2) emissions and large reductions in other greenhouse gas emissions.

Third, degrowth proponents generally favour stabilising the global population and ensuring a more egalitarian distribution of income and wealth, both globally (i.e., from North to South) and within individual nations. Some degrowth proponents believe a significant fall in the global population is essential.

Finally, degrowth proponents often emphasise that a failure to mitigate urgently the current global ecological challenges will inevitably slow, if not reverse, GDP growth, due to ever more disruptive and damaging impacts (e.g., more severe storms and droughts, sea level rise, massive crop failures, etc.) precipitating mass migration, increased conflict, economic shocks, financial instability and ineffective governance. In short, beyond a certain point, temperature increases will render further global growth impossible. This argument, while plausible, is not discussed here.

Decoupling

The concept of decoupling is pivotal to the debate between the advocates of green growth and degrowth (see Jackson, 2009; Hickel and Hallegatte, 2021; UNEP, 2011a; Ward et al., 2016). Put simply, decoupling 'is reducing the amount of resources such as water or fossil fuels used to produce economic growth and delinking economic development from environmental deterioration' (UNEP, 2011a, p.xi). Resources, in this context, embrace both renewable and non-renewable resources. The former include biotic resources, such as forests, animals and fish, along with renewable energy sources, such as solar, wind and geothermal.[3] Non-renewable resources include construction minerals, ores and industrial minerals, and fossil fuels.

Decoupling has various forms. First, there is a distinction between *resource* decoupling and *impact* decoupling. The former refers to delinking GDP from resource use, whether in aggregate or for specific material and energy resources (e.g., overall energy decoupling, fossil fuel decoupling, etc.); the latter refers to delinking GDP from environmental impacts (e.g., greenhouse gas emissions, ocean acidification, biodiversity loss, including the loss of insect pollinators, soil degradation and loss, air and water pollution, and ever-increasing waste), thereby reducing impacts per unit of output. Overall, the evidence points to a close correlation between aggregate resource use and environmental impacts, but actual impacts vary depending on the specific resource in question and the technologies employed (van der Voet, van Oers and Nikolic, 2004; Hickel and Kallis, 2020; Steinmann et al., 2017).

Second, there is a distinction between *relative* (or weak) and *absolute* (or strong). Relative decoupling implies that the growth in resource use and/or environmental impacts is slower than GDP growth (e.g., because of improved resource efficiency or substitution). For absolute decoupling, the rate of relative decoupling must exceed the rate of increase in GDP (i.e., resource use and/or environmental impacts must decline while GDP rises). As discussed later, while some relative decoupling has occurred globally (and within many countries) over recent decades, absolute decoupling (whether resource or impact) has been limited. In other words, per capita GDP growth globally, coupled with ongoing population growth, has generally exceeded improvements in overall resource efficiency and efforts to reduce environmental impacts.

The context for the current debate

Debates about the potential for humanity to overshoot critical biophysical limits at a planetary scale are not new. In 1798 Thomas Malthus published *An Essay on the Principle of Population*, in which he argued that the size of the human population would ultimately be limited by scarce resources, not least food supplies. To quote: 'The power of population is indefinitely greater than the power in the earth to produce subsistence for man' (1798, p.13). To date, Malthus has been wrong.

Almost two centuries after Malthus, Meadows et al. (1972) argued in *The Limits to Growth*, and in various subsequent publications (Meadows, Meadows and Randers, 1992, 2004), that long-term exponential GDP growth is impossible, given Earth's limited natural resources and constrained absorptive capacity. Indeed, the MIT team claimed that even under the most optimistic assumptions concerning the nature and pace of technological innovation, continuing economic and population growth globally would eventually lead to overshoot and collapse. Such claims proved to be highly controversial and were the subject of many sustained and detailed rebuttals (e.g., Cole et al., 1973). Such critiques – which covered a range of methodological, empirical and normative issues – led many policymakers globally to dismiss the core arguments in *The Limits to Growth* (and related publications) as seriously flawed and misguided.

In recent decades, however, concerns about humanity's severe and widespread ecological impacts have intensified. In short, there has been mounting evidence that humanity is harming vital biophysical systems, living beyond Earth's means (i.e., consuming or damaging beyond what nature can regenerate), and exceeding 'safe' planetary boundaries (Rockström et al., 2009a, 2009b; Steffen et al., 2015, 2018). According to a recent OECD report, for instance:

> While global GDP per capita increased by more than 60% between 1992 and 2014, natural capital stocks per capita declined by nearly 40%, undermining future economic growth and well-being. One million plant and animal species now face extinction. (OECD, 2021, p.6; see also Managi and Kumar, 2018)

> Green growth advocates believe that the fiscal and regulatory reforms needed for environmental sustainability will be unacceptable politically if citizens in high-income countries ... are confronted with a stark choice between ... environmental responsibility and ... continued improvements in living standards ...

Similar concerns have been raised by many other international organisations, along with scientific academies, governmental agencies and leading researchers.[4] There have also been various studies updating, and generally supporting, many of the assumptions and projections of Meadows et al. (e.g., Randers, 2008; Turner, 2008, 2019).

Broad areas of agreement

While the advocates of green growth and degrowth disagree about many things, there are also important areas of agreement (see, for instance, Hickel and Hallegatte, 2021; Hickel and Kallis, 2020; van den Bergh, 2017). These can be summarised as follows.

First, humanity faces many systemic complexities and multiple uncertainties – technological, ecological, social and political – with the potential for significant non-linear changes. Accordingly, the future cannot be fully known, the past may not provide a reliable guide to the future, and many surprises are likely, some positive, others negative. All this points to the need for a flexible and precautionary approach.

Second, there is a general acceptance that Earth, as a finite planet, exhibits various real, non-negotiable biophysical constraints. These include basic physical constraints. For instance, human settlements and related structures cannot get bigger indefinitely and non-renewable resources, if exploited continuously and not fully recycled or repurposed, will eventually be exhausted. Likewise, the (safe) absorptive capacities of Earth's biosphere are limited (e.g., the capacity to absorb greenhouse gas emissions and material waste), as are its regenerative capacities. These constraints must be respected if a modern industrial civilisation is to survive, let alone prosper. Against this, there is less agreement about where 'safe' boundaries should be drawn, what limits have already been exceeded, and the severity of the current biophysical risks. That said, few doubt the difficulties of forging a global path that is compatible with the full range of planetary and sub-planetary limits (Boston, 2011).

Third, there is broad agreement that the current global patterns of production and consumption are unsustainable ecologically. Moreover, supporting up to 10 billion people with an average per capita income of US citizens, and comparable per capita resource and energy use, is not feasible. Hence, significant changes are needed to investment flows, modes of production, transport and stationary energy systems, land management, and the use of material resources, both renewable and non-renewable. In particular, the global economy must be decarbonised (or 'defossilised') rapidly and a circular economy instigated, with minimal waste. These changes, it is generally accepted, will be impossible without globally coordinated, widely adopted and highly effective policy reforms and related behavioural changes. Current reform agendas fall far short.

Fourth, there is no dispute that significant and sustained absolute decoupling of resource

Table 1: Green growth versus degrowth: key issues, assumptions and claims

Issue	Green growth	Degrowth
Biophysical limits, including the absorptive and regenerative capacity of the biosphere	There are real, non-negotiable biophysical limits at multiple scales which is why global GDP growth must be 'green' if it is to continue indefinitely	There are real, non-negotiable biophysical limits at multiple scales which is why global GDP growth must discontinue, and sooner rather than later, in the interests of ecological sustainability and human wellbeing
Current ecological crises	There are multiple ecological crises; current global production and consumption patterns are not ecologically sustainable; significant policy changes are essential	There are multiple ecological crises; current global production and consumption patterns are not ecologically sustainable; radical policy changes are essential
Global population	The human population can be expected to stabilize at an ecologically sustainable level	Additional efforts are needed to stabilize the human population; some degrowth advocates favour a substantial fall in the human population by 2100
GDP per capita as a measure of economic progress	GDP per capita is a useful but inadequate measure; more comprehensive measures of progress and societal wellbeing are desirable	GDP per capita is neither a reliable measure of human wellbeing nor a proper focus for public policy; more comprehensive measures of progress and societal wellbeing are desirable
The desirability of further global GDP growth	Overall, GDP growth is welfare enhancing; prudent green growth strategies will accelerate the required technological transitions and generate higher long-term growth rates	Further GDP growth per capita is justified in low-income countries, but not in high-income countries. Continuing global GDP growth will make the required technological transitions harder by increasing aggregate demand for energy and natural resource, exacerbating harmful environmental impacts, and increasing the reliance on speculative negative emissions technologies
Constraints on global GDP growth	Assuming ecologically sound policies are adopted globally, the only long-term constraints on global GDP growth will be human creativity, technological innovation, and good governance; continued GDP growth can be expected in a fully circular, zero-carbon global economy	Fundamental biophysical constraints of various kinds will ultimately limit the capacity for further efficiency gains and resource substitution, thereby limiting further global GDP growth
Absolute decoupling	While the historical record provides no evidence of sustained absolute decoupling globally, the future can be different from the past. Rapid technological transitions are possible	The historical record provides no evidence to support the contention that long-term absolute decoupling is likely. Relative decoupling, however, has been occurring
Absolute resource decoupling	Absolute resource decoupling is technically feasible, but suitable policies will be needed to catalyse the required technological transitions	Absolute resource decoupling on the speed and scale required appears unlikely based on recent evidence. There are multiple behavioural, structural, institutional, and political barriers to rapid and sustained resource decoupling
Absolute impact decoupling	Absolute decoupling of global GDP growth and global GHG emissions is not only technically feasible, but with suitable policies can also be achieved at a rate sufficient to meet agreed global climate change targets and other important ecological goals	Absolute decoupling of global GDP growth and global GHG emissions appears unlikely based on recent evidence; rapid and sustained reductions in global GHG emissions to meet ambitious targets (e.g. a warming cap of 1.5°C) will require a significant decline in global GDP
Renewable energy technologies	Renewable energy technologies can power a modern industrial civilization	Some, but not all, degrowth proponents doubt whether renewable energy technologies can power a modern industrial civilization
Negative emissions pathways	Negative emissions pathways are technically viable and will become increasingly feasible economically	Both the technical and economic viability of negative emissions technologies are doubtful; some are highly speculative; it is too risky to rely on such technologies to achieve global GHG mitigation goals
Governance capacity and policy reform	Enough governments globally will design and implement sufficient 'green' policy reforms to enable sustained global GDP growth during the 21st century	The evidence to date raises serious doubts about the capacity and willingness of governments, whether democratic or otherwise, to implement the policy reforms needed for ecological sustainability
The damaging economic impacts of ecological problems	The negative impacts of climate change and other ecological problems have the potential to impede long-term global GDP growth which is why a green growth strategy is essential	The negative impacts of climate change and other ecological problems are likely to cause large-scale economic losses, damage critical infrastructure, and undermine existing social and political institutions

consumption and environmental impacts from global GDP growth is ecologically essential. Net zero greenhouse gas emissions globally, for instance, requires full decoupling, regardless of the level of economic activity. Plainly, this represents a demanding constraint. How best to respond remains hotly contested. Against this, there is no dispute that the pace of resource and impact decoupling can be changed and will, among other things, be influenced by the nature, scale and uptake of technological advances. That said, whether GDP growth can be rendered completely independent of environmental degradation remains uncertain.

Fifth, there is general agreement that the quest for ecological sustainability must not ignore other important goals (as reflected, for instance, in the Sustainable Development Goals), and especially the needs of the world's poorest citizens. This includes several billion people who currently lack access to electricity and proper sanitation, and nearly one billion people who experience regular or periodic hunger. It is recognised that ensuring an acceptable standard of living and universal access to basic services globally (e.g., education, health care, fresh water and energy) will require massive investment over a generation or more and almost certainly much higher GDP per capita in all low-income countries; achieving such outcomes will be challenging (see Millward-Hopkins et al., 2020). While degrowth advocates tend to be egalitarians and strongly support a just transition to a zero-emissions, circular and more inclusive economy, green growth advocates have widely divergent distributional preferences.

Finally, there is a partial consensus on the demand-side and supply-side policies required for greater sustainability. These include: better environmental governance, with improved goal setting, monitoring and reporting (see Petrie, 2021); 'green budgeting' (e.g., taxing/pricing environmental externalities such as greenhouse gas emissions, removing subsidies for the wasteful use of land, energy and natural resources, and robust resource rentals); a range of industry- and sector-specific measures; comprehensive regulatory measures to limit environmental harms, protect biodiversity and enhance the efficient use of resources (e.g., strict efficiency standards for all buildings and appliances, requirements for firms to recycle their products along their entire lifetimes, standardised requirements to lower the transaction costs of technology and network integration, etc.); and higher investment in environmentally relevant research and development. Many degrowth proponents go much further, arguing for comprehensive national planning, massive public investment (with long-term horizons) and vigorous 'technology-forcing' regulation, if not the fundamental rethinking of modern capitalist institutions and market-oriented policies (e.g., monetary and fiscal policies, the nature and role of property rights, the operation of major financial institutions, etc.).

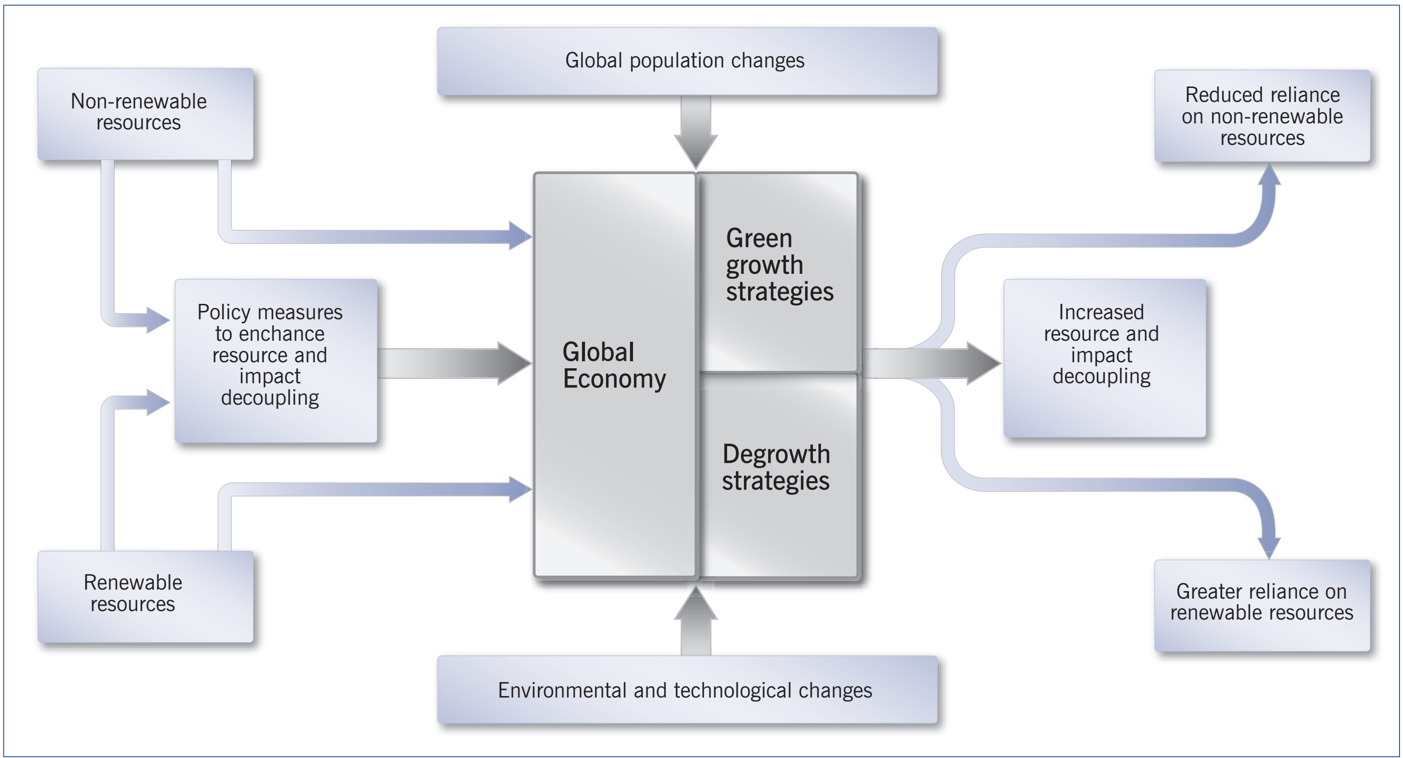
Key areas of disagreement

Turning now to the empirical and normative issues at the centre of the green growth–degrowth debate, these are summarised briefly below (see also Table 1), followed by a more detailed discussion of absolute decoupling.

The overall long-term desirability of GDP growth

While both schools of thought acknowledge the limitations of GDP as an indicator of societal progress and reject *unconditional* GDP growth, green growth advocates believe that GDP growth, at least of a particular kind, not only enhances overall human wellbeing and reduces poverty, but also facilitates improved environmental outcomes and more rapid technological and structural transitions. Indeed, if properly regulated, growth will both drive the required ecological transformation and trigger new sources of growth. By contrast, it is argued that a degrowth strategy – to the extent that a long-term contraction of GDP can be engineered, whether across the OECD or globally, perhaps by comprehensive planning and/or quantitative caps on resource use – will increase unemployment and inequality, reduce resource efficiency, undermine public finances, diminish the capacity to invest in resilient, climate-aligned infrastructure, and provoke deep political tensions. Accordingly, deliberately contracting GDP is neither necessary nor sufficient for ecological sustainability; economic growth should thus

Figure 1: The global economy and resource and impact decoupling



remain a core policy goal, including in high-income countries.

As noted earlier, degrowth proponents disagree on all these points. In particular, they reject the proposition that GDP growth will help catalyse the required technological transitions, including a radical recomposition of global consumption patterns; on the contrary, it will make such transitions harder by increasing the aggregate demand for resources and energy.

The speed, scale and scope of the required technological innovations

Overall, green growth advocates believe that current and likely future technologies, if supported by suitable policies, can enable both absolute resource and absolute impact decoupling to occur at a speed, scale and scope necessary to achieve crucial ecological goals (e.g., global decarbonisation at a rate sufficient to avoid warming of more than 1.5°C or 2.0°C). For various reasons, many degrowth advocates doubt such assumptions. These include the limits to resource substitutability, the constraints imposed by the laws of thermodynamics on efficiency, the challenges of path dependence (e.g., due to the long lifetime of most physical infrastructure, including carbon-intensive energy systems), and related barriers to socio-technical transitions (see Geels and Schot, 2007; Geels et al., 2017; also Chapman, 2019).

> ... questions arise over proposals to rely heavily on bioenergy with carbon capture and storage ... to assist with the energy transition and subsequently to secure negative net emissions globally ...

Prevarication will only increase the overall economic and other sacrifices required. Equally, some doubt the political viability of critical aspects of the green growth approach (e.g., because of the power of vested interests).

The political feasibility of the respective strategies

Green growth advocates believe that the fiscal and regulatory reforms needed for environmental sustainability will be unacceptable politically if citizens in high-income countries (and subsequently elsewhere) are confronted with a stark choice between, on the one hand, environmental responsibility and, on the other, continued improvements in living standards (e.g., as reflected in higher per capita incomes, comprehensive social services, adequate pensions, etc.). Moreover, a degrowth strategy is considered politically implausible: proactively engineering a long-term contraction of GDP while simultaneously transforming economic structures and energy systems and redistributing income and wealth to low-income citizens would require policy measures well beyond those possible in a democracy, certainly in peacetime.

Degrowth advocates dispute such claims, arguing that a completely new 'social contract' is imperative and, ultimately, unavoidable.

Psychological dispositions

Standing back from all the particulars of the debate, the respective schools of thought diverge in their psychological dispositions, or mental models. First, imagination: degrowth advocates find it hard to imagine a world where GDP growth continues more or less indefinitely, while green growth advocates find it equally hard to conceive of a world without ongoing GDP growth (e.g., some kind of stable or steady-state economy). Second, optimism: relative to many of their degrowth counterparts, (most) green growth advocates tend to be technological optimists, with a high confidence in human ingenuity. Also, to the extent that both camps include optimists, their hopes lie in different futures for humanity. That said, some degrowth advocates are undoubtedly pessimistic, if not fatalistic, about humanity's prospects.

Absolute decoupling

At the core of the debate over absolute decoupling are several crucial questions, none of which are amenable to a simple answer. First, what rates of resource and impact decoupling are needed to achieve various desired ecological outcomes (e.g., the key goals of the Paris Agreement and other relevant international instruments)? Clearly, answers will depend, among other things, on exactly how such goals are specified, including the level of acceptable risk. Second, what assumptions can reasonably be made about the speed, scope and scale of resource and impact decoupling by, say, 2050? And are the optimistic claims of many green growth advocates about both the potential and likely rates of decoupling justified? Third, and related, would global GDP growth, other things being equal, facilitate a significantly higher sustained rate of both resource and impact decoupling than would otherwise be possible (e.g., by increasing relevant public and private investment, encouraging more rapid shifts in consumption patterns, and enabling faster technological and structural transitions)? Alternatively, will any additional efficiency gains associated with GDP growth be overwhelmed by the tendency for such growth to increase overall environmental impacts (via the rebound effect or Jevons paradox)?[5] This section offers some brief reflections on the issues surrounding resource and impact decoupling. Figure 1 provides a simplified representation of the process of resource and impact decoupling at the global level.

Absolute resource decoupling

Natural resource use globally reached an estimated 100 billion metric tons annually in 2020. This is claimed to be about double the maximum sustainable boundary level (Bringezu, 2015; Bringezu et al., 2017; Hoekstra and Wiedmann, 2014; Hickel and Kallis, 2020; Hickel and Hallegatte, 2021). If so, a massive reduction in aggregate resource use will be necessary during the 21st century, as well as large shifts in consumption patterns to reflect the relative scarcity of different resources. Achieving such changes, even with much lower (or zero) GDP growth, will require dramatic gains in resource efficiency (well above average historical rates), large-scale substitution, and a huge increase in resource recycling. Realistically, from a technical perspective, how rapidly could such changes be achieved? And could the required transformation occur within the very limited time frame available if the global economy continued to grow at a moderate pace?

Degrowth advocates are pessimistic. First, it is acknowledged that a relative decoupling of global GDP from total world material and energy consumption has occurred since the mid-20th century, with an expanding gap between GDP and resource use. But the pace of dematerialisation of GDP growth slowed in recent decades (Hickel and Kallis, 2020). More importantly, there is no evidence yet, despite the large shift in consumption towards services and away from manufacturing, that the world economy has experienced sustained absolute resource decoupling (Ward et al., 2016). At best, such decoupling has been limited to specific countries (e.g., Germany) and certain resources (e.g., via efficiency gains and/or substitution). For the future to be radically different, a massive upswing in the pace and diffusion of technological change and related material efficiency improvements would be needed, one sufficient and sustainable in the long term to negate the Jevons paradox and counteract the impact of continuing global population growth (see Schandl et al., 2016). Degrowth advocates doubt whether such outcomes are realistic.

Second, and related, it is argued that permanent decoupling, both absolute and relative, is 'impossible for essential, non-substitutable resources because the efficiency gains are ultimately governed by physical limits' (Ward et al., 2016). Such resources include land, fresh water, soil and a stable climate: they lack obvious substitutes (excluding other planets), yet are essential to meet basic human needs. Moreover, physiological constraints govern the efficiency of water use by crops and there are photosynthetic limits to plant productivity. Many non-renewable resources are, of course, substitutable, but their substitutes may also be non-renewable and thus limited in supply.

Third, some degrowth advocates highlight both the technical (e.g., thermodynamic) and societal limits to a largely circular economy. Currently, aside from biomass, less than 10% of all materials processed globally are recycled. Further, many materials cannot readily be recycled or reused, high levels of path dependence will slow the pace of recycling where it is technically viable, many countries and sectors are unlikely to follow best practice in efficient resource use, and in-use stocks of materials (e.g., physical infrastructure and buildings) continue to grow, thus constraining the scope for circularity. Yet without high levels of circularity, certain non-renewable resources – even gravel and sand – will eventually run out.

In brief, green growth advocates generally respond to these concerns as follows. They accept that some essential resources are non-substitutable and that, thus far at least, population growth and increased affluence globally have nullified (most of) the resource efficiency gains from technological innovation, but they maintain that the future can be different. For one thing, the current technical limits to improved efficiency and substitution are far from being reached; for another, breakthrough technologies (e.g., nuclear fusion) could extend these limits radically. Hence, hitherto unprecedented gains in resource efficiency (e.g., several times higher annually than the historical average) are technically possible, thereby making rapid absolute resource decoupling a realistic option (Hatfield-Dodds et al., 2015; Schandl et al., 2016; see also the reply to both from Lenzen et al., 2016). It is accepted, however, that this would require major policy reforms globally, massive investments in research and development, and the swift uptake and diffusion of many current and new technologies.

Of course, much the same requirements would apply under a degrowth scenario. Degrowth by itself is thus no substitute. Yet, as noted earlier, securing sustained political support for transformative policy reforms may well be much harder if governments are simultaneously pursuing a long-term strategy of economic contraction (or even zero GDP growth), let alone seeking to implement fundamental changes to the core institutions of modern capitalist economies.

> Given the existing ecological crises, both green growth and degrowth advocates readily accept the need for radical technological changes, including rapid de-carbonisation and greatly enhanced energy and resource efficiency.

Absolute impact decoupling

Any limits to absolute or relative resource decoupling will necessarily constrain the scope for absolute impact decoupling, even with a concerted shift to lower-impact resources and different consumption patterns. Equally important, absolute impact decoupling (e.g., to meet global greenhouse gas mitigation goals) will depend heavily on whether: a) global energy and transport systems can be rapidly and fully decarbonised (e.g., by 2050 or soon after); and b) there is a significant reduction in the energy intensity (the amount of energy used per unit of output) of the global economy (e.g., via improved energy-service efficiency and conservation). Degrowth advocates accept the possibility of absolute decoupling of greenhouse gas emissions from global GDP growth, but doubt whether the required magnitude and speed of such decoupling is technically possible and/or likely in practice even if technically possible (e.g., because of political resistance and inappropriate policy settings) (Hickel and Kallis, 2020).

First, questions arise over proposals to rely heavily on bioenergy with carbon capture and storage (BECCS) to assist with the energy transition and subsequently to secure negative net emissions globally (that is, later in the century to address the likely overshooting of global warming limits) (Anderson and Peters, 2016; McLaren and Markusson, 2020). BECCS involves sequestering CO_2 from the atmosphere via large plantation forests, harvesting the trees, burning them for energy, and then capturing and storing the released CO_2. Yet any significant reliance on BECCS would require massive forest plantations covering extensive areas of land, with likely negative implications for global food production and biodiversity loss. Success would also depend on large-scale, permanent and secure storage of CO_2. The technical challenges to such a strategy are likely to be daunting, yet even more essential to overcome under a scenario involving continuing global economic growth.

Second, degrowth advocates argue that aggressive mitigation strategies to achieve net zero CO_2 emissions by around 2050 without BECCS (or other negative emissions technologies) will face formidable hurdles. If global GDP grows at an average annual rate of about 3% over coming decades, it is estimated that to have a roughly two-thirds chance of avoiding warming of more than 1.5°C, the rate of decoupling annually must be at least 10% – or around 7% to meet a 2.0°C warming cap (Hickel and Kallis, 2020). Even greater decoupling rates will be needed in high-income countries if such countries are to make a fair contribution to the global mitigation effort (and/or reduce the risks of overshooting the warming caps). With zero or very low annual global growth, the required decoupling rates would be somewhat lower. Even so, the required rates would exceed anything hitherto achieved globally by a large margin. Might this be possible?

There are various studies using different models and assumptions (including varied growth assumptions) exploring this question (IPCC, 2018). In short, any potentially plausible scenario involving the rapid absolute decoupling of greenhouse gas emissions from GDP growth requires most, if not all, of the following elements:

- a massive expansion of renewable energy technologies (RETs), especially solar and wind, and related energy storage capacity, with total renewable energy capacity needing to double every five to eight years by 2050 (depending on trends in aggregate energy demand);
- the complete decarbonisation of the world's transport fleets (including around one billion cars and 400 million trucks and vans) and key industrial processes (e.g., the production of steel and cement);
- large-scale afforestation and soil regeneration;
- a significant reduction in the energy intensity of the global economy;
- substantial efficiency improvements in the use of non energy-related resources;
- significant changes in food production (e.g., away from livestock agriculture);
- minimising any rebound effects; and
- various behavioural, social, cultural and institutional changes to enable systemic reforms and accelerate the diffusion of new technologies (see, for instance, Grubler et al., 2018; IPCC, 2018).

Degrowth advocates doubt whether many of these outcomes are achievable, particularly under scenarios involving significant economic growth. Take, for instance, a rapid transition to a 100% reliance on RETs and

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the related uptake of electric vehicle technologies (EVTs). According to many degrowth advocates, not only will such transitions require substantial additional overall electricity-generating capacity (even more so with economic growth), but they will also require hitherto unprecedented levels of investment in new energy systems. It is claimed that the scale, complexity, and cost of the energy transition, including likely information asymmetries, supply chain problems, bottlenecks and path dependencies, has been seriously underestimated by green growth advocates. Replicating the remarkably efficient energy storage function of fossil fuels, whether via electro-chemical batteries, pumped hydro storage or other means, will be massively challenging technically, as well as costly economically and in resource terms (Palmer and Floyd, 2020). In this respect, Aotearoa New Zealand is relatively fortunate given its substantial hydro storage capacity and the option to develop pumped hydro.

Related to this, many degrowth proponents argue that various natural resources essential for RETs and EVTs, including many 'critical raw materials' (e.g., cobalt, lithium, rare earth elements, etc.), are relatively scarce, often environmentally and socially damaging to exploit, and sometimes located in areas of political instability (Michaux, 2021; Seibert and Rees, 2021; see also Sovacool et al., 2020). Another common claim is that RETs cannot power a modern industrial civilisation without some reliance on fossil fuels. This is because – or so it is argued – some RETs (e.g., corn ethanol, biodiesel and solar PV) have low energy returns on energy invested (EROEI or EROI), some raise energy storage issues (e.g., wind and solar), and some have limited lifespans and/or significant recycling costs (Ferroni and Hopkirk, 2016; Hall, 2017; Murphy and Hall, 2010). Aside from this, many degrowth advocates doubt that current market-based or neo-liberal policy approaches can achieve the non-marginal, disruptive, system-wide re-engineering of global energy systems by 2050.

Unsurprisingly, these claims have generated a large literature, with substantial debate over numerous technical, methodological and measurement issues (see, for instance, Fthenakis et al., 2021; Raugei et al., 2017). Assessing all the claims and counterclaims of energy economists and other experts is not possible here. Importantly, however, concerns about low EROI for RETs have been vigorously rebutted point by point (see Diesendorf, 2021; Diesendorf and Wiedmann, 2020; Raugei and Leccisi, 2016; Raugei et al., 2017). Much the same applies to other key objections to relying fully on RETs and EVTs (note that EVs have energy conversion efficiencies about three to five times those of internal combustion engines). It is accepted, however, that the projected demand by 2050 for some material resources may exceed currently known reserves (Bobba et al., 2020; Junne et al., 2020) and that much better environmental regulation of mining is vital. But technological innovations over the coming decades, including recycling and substitution, and efforts to diversify supply sources are expected to ease critical resource pressures.

Such rebuttals have given green growth advocates confidence that a growing global economy can be powered 100% by RETs for some time, if not indefinitely, and that the investment funds required for the massive energy transition can be mobilised, as long as governments implement supportive regulatory and pricing policies. Indeed, the transition is already well underway, albeit too slowly currently to meet ambitious global mitigation targets (International Energy Agency, 2021).

Whether, and to what extent, the global transition will accelerate during the 2020s depends heavily on policy settings in the major economies, especially the US, EU, China and India, and the investment decisions of large international corporations and financial institutions. Currently, the outlook is mixed. If the Biden administration fails to secure congressional support for significant federal decarbonisation measures and/or if the US Supreme Court blocks vital regulatory initiatives, other major global players, particularly China, may be less inclined to take bold measures. In this scenario, the global transition will be much slower than desirable. Against this, Russia's invasion of Ukraine may spur investment in RETs and EVTs, contributing to significant technological innovations. Realistically, what Aotearoa New Zealand does on the climate mitigation front will have little global impact, except perhaps for livestock emissions. But this does not lessen the long-term economic wisdom of, let alone the moral case for, radical policy measures to enhance ecological sustainability.

Conclusion

There is increasing recognition that humanity must live within real, non-negotiable biophysical constraints at multiple scales. Failure to do so will eventually prevent, if not reverse, economic and social progress. But what level and form of global economic activity is ultimately compatible with ecological sustainability remains uncertain. That said, continued global GDP growth over an extended time horizon – and even maintaining current levels of economic activity – will only be possible under strict conditions. These include adequately protecting the resilience of vital ecosystem services and biophysical systems. Currently, these conditions are not being met.

Given the existing ecological crises, both green growth and degrowth advocates readily accept the need for radical technological changes, including rapid decarbonisation and greatly enhanced energy and resource efficiency. They differ, however, over whether ecological sustainability will also require significantly (and perhaps rapidly) slowing, if not reversing, global GDP growth and the political feasibility of their respective policy approaches.

Assessing the validity of these contrasting perspectives is difficult because of multiple deep uncertainties. Two such uncertainties are critical. The first concerns the speed with which current and future breakthrough technologies are developed and comprehensively applied, and hence the potential pace and scale of absolute resource and impact decoupling. The second concerns the capacity of current governance arrangements, both global and national, to design and implement policy frameworks sufficient to catalyse and accelerate the necessary energy and resource transitions, including widespread and substantial changes in consumer behaviour. In both cases, the judgements of experts appear to be influenced not only by evidential considerations, but also by philosophical, ideological and psychological dispositions. In short, technological optimists, neoclassical economists, and those who doubt the political viability of economic contractionism (whether in democracies or autocracies) are drawn more strongly to the green growth camp.

Leaving technological uncertainties aside, our governance arrangements, both democratic and otherwise, remain deeply problematic. Here the evidence points unequivocally to a fundamental mismatch between the scale of humanity's ecological challenges and the capacity and willingness of citizens and policymakers to respond (Hagens, 2020). If this mismatch persists for a decade or more – perhaps due to a combination of cognitive biases (including myopia and denial), ideological preferences, geo-political conflicts, short-term electoral pressures and powerful vested interests – then the required transitions may be too slow. In this scenario, the ecological crises will deepen and the negative impacts will increase, eventually causing large-scale damage to critical physical infrastructure and widespread supply disruptions. At that point, global degrowth may become inevitable (Keen, 2021). The resulting social and political tensions will be immense, and probably unmanageable. In short, modern civilisation could destroy itself. Such an outcome, while tragic, would not be totally unprecedented. Previous civilisations have mismanaged their environments and suffered dire consequences – the Sumerians, Babylonians and Mayans, to name but a few (Diamond, 2005).

But suppose enough governments respond swiftly and effectively and the required systemic, technological and behavioural changes occur within ecologically sustainable time frames: is indefinite GDP growth then a plausible scenario? Interestingly, some ardent supporters of green growth say no. To quote Nicholas Stern: 'Strong growth, of the right kind, will be both necessary and feasible for many decades … [But] This is not to claim that the world can continue to grow indefinitely … A picture of indefinite expansion is an implausible story of the future' (Stern, 2009, p.10).

Yet perhaps humility, in the face of deep uncertainty and complexity, requires a more equivocal answer.[6] As Hickel and Kallis (2020) acknowledge, 'as long as ultimate limits in efficiency and substitution have not been reached', the question cannot be answered definitively. That, in my view, constitutes a prudent response.

Nevertheless, to minimise the risk of a catastrophic ecological collapse globally, prudence also requires immediate, bold and transformative actions, at all levels of society and in every sphere of economic and social life. As a recent editorial in the authoritative journal *Nature* (2022, p.361) concluded, 'the world is running out of time'.

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1 See, for instance, Carney, 2021; Fiorino, 2018; Hall, 2016; Pollin, 2018; Stern, 2007, 2009.
2 See, for instance, Brown et al., 2011; Costanza et al., 2014; Hagens, 2020; Hickel and Kallis, 2020; Hickel, 2021; Kallis, 2011; Jackson and Victor, 2019; Mastini et al., 2021; Murphy et al., 2021; Otero et al., 2020; Pollitt, 2022; Schröder and Strom, 2020; Vogel et al., 2021; Ward et al., 2016; Wilkins and Murphy, 2021.
3 But note that expanding the reliance of the global econoy on solar and wind energy requires the exploitation of many non-renewable, and hence finite, resources, as discussed later.
4 See, for instance, Arrow et al., 2004; Bradshaw et al., 2021; Dasgupta, 2021; Folke et al., 2021; IPCC, 2018, 2021, 2022; IPBES, 2019; Stern, 2007; UNEP, 2011a, 2011b.
5 The Jevons paradox or rebound effect involves the tendency for cheaper and more energy-efficient services, whether arising from technological progress or policy changes, to increase the demand for energy and other resources, thus resulting in smaller reductions in overall energy consumption than otherwise expected.
6 On the need for and virtues of humility in the public sphere, see Annala et al., 2021.

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