Is green growth happening? An empirical analysis of achieved versus Paris-compliant CO_2–GDP decoupling in high-income countries

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Summary

Background Scientists have raised concerns about whether high-income countries, with their high per-capita CO_2 emissions, can decarbonise fast enough to meet their obligations under the Paris Agreement if they continue to pursue aggregate economic growth. Over the past decade, some countries have reduced their CO_2 emissions while increasing their gross domestic product (absolute decoupling). Politicians and media have hailed this as green growth. In this empirical study, we aimed to assess whether these achievements are consistent with the Paris Agreement, and whether Paris-compliant decoupling is within reach.

Methods We developed and implemented a novel approach to assess whether decoupling achievements in high-income countries are consistent with the Paris climate and equity goals. We identified 11 high-income countries that achieved absolute decoupling between 2013 and 2019. We assessed the achieved consumption-based CO_2 emission reductions and decoupling rates of these countries against Paris-compliant rates, defined here as rates consistent with national fair-shares of the remaining global carbon budgets for a 50% chance of limiting global warming to 1·5°C or 1·7°C (representing the lower [1·5°C] and upper [well below 2°C] bounds of the Paris target).

Findings The emission reductions that high-income countries achieved through absolute decoupling fall far short of Paris-compliant rates. At the achieved rates, these countries would on average take more than 220 years to reduce their emissions by 95%, emitting 27 times their remaining 1·5°C fair-shares in the process. To meet their 1·5°C fair-shares alongside continued economic growth, decoupling rates would on average need to increase by a factor of ten by 2025.

Interpretation The decoupling rates achieved in high-income countries are inadequate for meeting the climate and equity commitments of the Paris Agreement and cannot legitimately be considered green. If green is to be consistent with the Paris Agreement, then high-income countries have not achieved green growth, and are very unlikely to be able to achieve it in the future. To achieve Paris-compliant emission reductions, high-income countries will need to pursue post-growth demand-reduction strategies, reorienting the economy towards sufficiency, equity, and human wellbeing, while also accelerating technological change and efficiency improvements.

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Introduction

High-income countries, with their high per-capita CO_2 emissions, must reduce their emissions at an extremely fast rate to comply with the climate targets and equity commitments of the Paris Agreement. Economic growth makes such rapid emission reductions very difficult to achieve. The problem is that, under any given scenario of technological change, an increase in aggregate production and consumption entails more energy demand, and consequently more CO_2 emissions, than would be the case without such an increase (appendix p 6).[1–4] Therefore, there are major concerns as to whether it is possible for high-income countries to uphold their obligations under the Paris Agreement while continuing to pursue economic growth.[4–10]

Politicians in high-income countries have typically responded to this problem by insisting that economic growth can be made green. For evidence, they point to countries that have recently achieved absolute decoupling of gross domestic product (GDP) from trade-corrected CO_2 emissions (ie, increasing GDP alongside declining emissions).[11–13] Several commentators have cited these achievements as examples of green growth; perhaps most prominently is a 2022 Financial Times article claiming that "green growth is already here", and "may take us to net zero all on its own".[14]

In this study, we assess whether high-income countries have achieved what can reasonably be considered green growth, or whether they are likely to achieve it in the future. To do this, we need a meaningful benchmark of what it would take for growth to be green.

It has long been understood that emissions can decline alongside growing GDP, specifically when the percentage increase in GDP is outweighed by a larger

See Online for appendix

Research in context

Evidence before this study

Scientists have warned that growth can only be green if decoupling is fast enough to reduce emissions in line with the Paris Agreement. Previous studies have compared national decoupling-based emission reduction rates to the global average rates required for meeting particular climate targets, but not to the (much faster) rates required in high-income countries to align with the climate and equity commitments of the Paris Agreement.

Added value of this study

Our study addresses this gap by calculating nation-specific emission reduction rates consistent with the Paris climate and equity commitments, and decoupling rates required to achieve such Paris-compliant emission reductions alongside continued economic growth (ie, required for what could legitimately be called green growth).

Implications of all the available evidence

Decoupling achievements in high-income countries fall dramatically short of Paris-compliant emission reductions. Green growth is therefore not occurring, and appears out of reach for high-income countries. Our findings suggest that the continued pursuit of economic growth in high-income countries is at odds with the climate and equity commitments of the Paris Agreement. Paris-compliant mitigation in high-income countries will require post-growth demand-reduction strategies in addition to technological decarbonisation efforts.

percentage reduction in the emissions intensity of GDP. Such absolute decoupling is of course necessary for green growth, but it is not sufficient. It is not enough to just reduce emissions by any amount; countries need to reduce their emissions to net zero, and fast enough to limit global warming to 1·5°C or at least well below 2°C in an equitable manner, as per the requirements of the Paris Agreement. Insufficient emission reductions will result in dangerous and possibly catastrophic global warming and exacerbate climate injustice. Such a scenario cannot be considered green. Several studies have established that the benchmark for green growth should therefore not just be about whether countries achieve absolute decoupling, but whether they achieve sufficiently rapid absolute decoupling to meet Paris climate and equity commitments.[5,7,15] It is ultimately a question of speed.

We developed a novel empirical approach for assessing whether high-income countries are decoupling GDP from CO_2 emissions fast enough to meet the climate and equity targets of the Paris Agreement. We identified all Annex-1 countries that have recently achieved sustained reductions in consumption-based CO_2 emissions alongside continuous GDP growth. We assessed whether the mitigation rates these countries achieved through such absolute decoupling are consistent with their fair-shares (defined here as population-proportionate shares) of Paris-compliant carbon budgets, as a basic criterion for green growth. Finally, we compared these countries' achieved decoupling rates to the future decoupling rates that would be required to meet their fair-share carbon budgets alongside continued economic growth, to evaluate whether green growth is within reach.

This research addresses an important gap. Previous studies have compared achieved national decoupling rates or mitigation rates to the global average rates required for 1·5°C or 2°C,[7,11,16,17] but not to the nation-specific requirements that result from the equity commitments of the Paris Agreement. These equity commitments are crucial for protecting the prospects for development and poverty eradication in lower-income countries. Furthermore, several previous analyses of absolute decoupling, or of emission reductions in the context of decoupling, have not excluded periods of recession (which by definition are not absolute decoupling, and where emission reductions cannot be attributed to decoupling alone), and have not excluded countries where emissions have formerly decreased but recently plateaued or increased (ie, no longer absolute decoupling).[8,11–13]

Methods

Identifying high-income countries that have recently achieved absolute decoupling

For the purposes of this study, we defined absolute decoupling as a sustained reduction trend in consumption-based CO_2 emissions alongside simultaneous continuous increases in real GDP.

We considered sustained reduction trends in emissions (here, 7 years), because informing reliable multidecade mitigation strategies requires a robust reduction signal. To identify overall reduction trends despite year-on-year fluctuation, and to distinguish reduction trends from plateauing or rebounding trends (which regression techniques alone might not capture), we considered the symmetric 5-year moving average (3-year average at the start and end of the time series) of annual emissions data. We primarily considered consumption-based CO_2 emissions (rather than territorial emissions), because in a globalised economy, national contributions to global emissions (reductions) need to reflect emissions embodied in trade. Territorial emissions are less suitable, because they do not capture (changes in) imported goods and services, or offshoring of industrial production (appendix pp 11–13).[7,13] We considered continuous year-on-year increases in GDP, because this is what green growth proponents seek to achieve, and because even a short-term reduction in GDP is considered a crisis (and can cause profound hardship) in the current economic system.

On the basis of this definition, and focusing on high-income countries, we looked for absolute decoupling

among all Annex-1 countries for which data were available (36 countries), using GDP data (GDP at purchaser's prices in constant 2015 prices in US dollars) from the World Bank[18] and CO_2 emissions data from the Global Carbon Project.[19–22]

We analysed recent achievements of absolute decoupling, to assess the near-term mitigation and decoupling requirements for green growth against relevant (recent) historical precedents. For this purpose, we considered the period from 2013 to 2019, after the 2008–09 financial crisis and its aftermath (which in many countries continued until as late as 2012, in some countries even longer), and before the COVID-19 crisis (which caused recessions in most countries; appendix p 2).

Estimating achieved rates of emission reductions, GDP growth, and decoupling

We considered mitigation rates m in terms of year-on-year relative reduction rates (or negative relative change rates) in consumption-based emissions.

We defined decoupling as a decrease in the carbon intensity of GDP, that is to say a decrease in CO_2 emissions per unit of GDP. The decoupling rate d is then defined as the relative reduction rate in the carbon intensity of GDP. This definition conceptualises relative decoupling ($g>d>0$ and $m<0$) and absolute decoupling ($d>g>0$ and $m>0$) as special cases of the general case of decoupling ($d>0$), and ensures that the decoupling rate is well defined for growing or declining emissions and growing or declining GDP (where g is the GDP growth rate). Moreover, this definition enabled us to calculate decoupling rates implied in pathways or scenarios of emissions and GDP, or to calculate emissions pathways from scenarios of decoupling rates and GDP. It is important to note that the inverse inference is not valid; pathways of GDP cannot reasonably be inferred from assumed emissions pathways and decoupling rates because emissions are the outcome of economic activity, not the other way around, and because decoupling reflects both physical and monetary changes in the economy.

For each country, we estimated annualised compound 2013–19 mitigation rates using linear regression on the negative natural logarithm of CO_2 emissions,[20] GDP growth rates using linear regression on the natural logarithm of GDP, and decoupling rates using linear regression on the negative natural logarithm of the carbon intensity of GDP. For simplicity, we will refer to these as 2013–19 average rates (noting they are technically annualised compound rates).

Global climate targets

Our primary analysis focused on a 50% chance of limiting global warming to 1·5°C, as aspired to in the Paris Agreement, and reaffirmed in the Glasgow climate pact. For comparison, we repeated the analysis for a 50% chance of staying under 1·7°C, operationalising the minimum Paris target of keeping global warming to "well below 2°C".[23] We note however that global warming of 1·7°C is extremely harmful and dangerous,[24] and should not be accepted.

Estimating fair-share national carbon budgets

We operationalised national climate targets in terms of national fair-shares of the remaining global carbon budgets for a 50% probability of limiting global warming to 1·5°C or 1·7°C, using the Intergovernmental Panel on Climate Change (IPCC)[25] estimates of the remaining global carbon budgets from 2020 (appendix p 3). We derived national fair-shares by allocating global carbon budget shares in proportion to each country's share of the global population[26] (averaged between 2020 and 2050), using the United Nations'[27] historical population estimates (for 2020–21) and the medium fertility population projection (2022–50).[28] This operationalisation of the Paris Agreement[29] commitment to reducing emissions in line with common but differentiated responsibilities should be seen as a minimum interpretation of equity regarding future mitigation, taking historical carbon debt to be a separate issue that must be compensated in other ways (appendix pp 8–10).

The fair-share national carbon budgets are defined from 2020 to the time of global net zero. To obtain a country's remaining fair-share national carbon budgets as of 2023, we subtracted its cumulative 2020–22 consumption-based CO_2 emissions from its 2020 fair-share national carbon budget. Given that our dataset of consumption-based emissions extended only until 2020, we estimated 2021 and 2022 consumption-based CO_2 emissions on the basis of data or estimates of GDP and carbon intensities of GDP. Our estimates of 2021 and 2022 carbon intensities of GDP, in turn, were computed as an extrapolation of the 2013–19 trends. Our estimates of 2022 GDP data were obtained by multiplying 2021 GDP data (from the World Bank) with the ratio of 2022 GDP forecasts to 2021 GDP data (on the basis of OECD[30] data and forecasts).

Emissions pathways, mitigation rates, and decoupling rates consistent with fair-share national carbon budgets

We calculated national CO_2 emissions pathways consistent with national carbon budgets on the basis of Raupach[31] curves. For each country, we thus computed a fair-share emissions pathway, starting from current emissions via a smooth transition from the 2013–19 average mitigation rate to an asymptotic mitigation rate, with ramp up starting in 2023, such that cumulative emissions under that pathway meet a given fair-share national carbon budget from 2023 (appendix pp 3–5).

This method is consistent with a limited level of deployment of negative-emission technologies, up until a level that balances residual, impossible-to-eliminate CO_2 emissions (such as in cement production), thus bringing overall CO_2 emissions from fossil fuels and industry down to net zero. However, net-negative CO_2 emissions are precluded, given the profound risks and

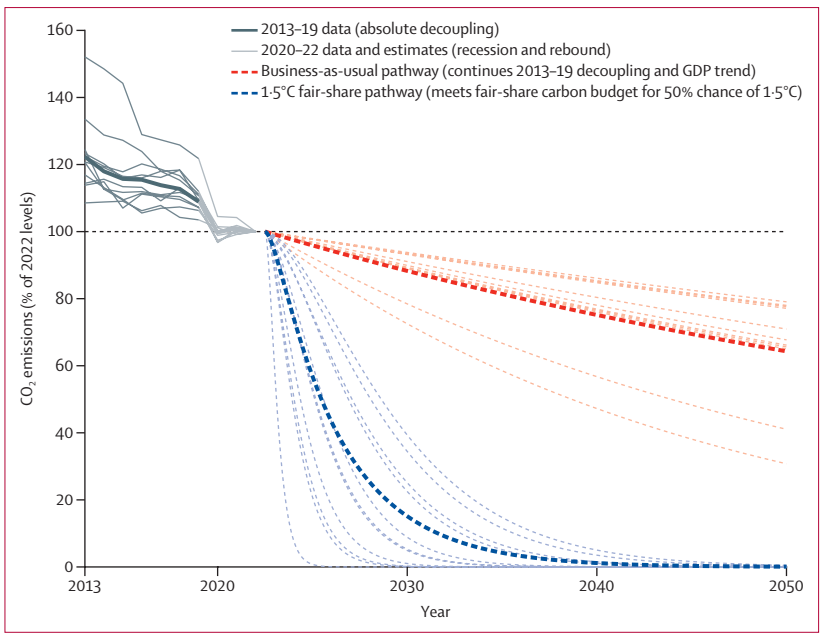

***Figure 1*: Emission reductions achieved in high-income countries through recent absolute decoupling are highly insufficient for complying with their fair-shares of the 1·5°C global carbon budget**
Empirical data and future scenarios of consumption-based CO_2 emissions (expressed as percentages of 2022 levels) for the 11 high-income countries that have recently achieved absolute decoupling (thin curves), and their population-weighted average (bold curves) are shown. Data for the absolute decoupling period (2013–19) are shown in dark grey, with data and estimates for the recession and rebound period (2020–22) shown in light grey. The dashed red curves show projected future emissions for a continuation of country-level 2013–19 average GDP growth rates and decoupling rates (business as usual). The dashed blue curves show emissions pathways that would limit the cumulative future emissions of countries to their respective fair-shares of the remaining global carbon budget for a 50% chance of a maximum increase of 1·5°C. Differences between different country pathways (thin curves) reflect differentiated mitigation achievements and fair-share mitigation requirements (not uncertainty as such). GDP=gross domestic product.

challenges associated with large-scale deployment of negative-emission technologies (appendix p 15).[32–35]

For each country, the required mitigation rates, that is the mitigation rates required to deliver the fair-share emissions pathway, were calculated as the year-on-year relative emission reduction rates under that pathway.

The required decoupling rates (ie, the decoupling rates that would be required to deliver the fair-share emissions pathway in a scenario of continued GDP growth) were calculated as the year-on-year relative reduction rates of the carbon intensities of GDP implied in the combination of the fair-share emissions pathway and a GDP pathway of continued growth at the 2013–19 average growth rate.

Business-as-usual emissions pathways

For comparison, we also calculated business-as-usual emissions pathways for each country, assuming a continuation of 2013–19 average GDP growth rates and decoupling rates (appendix p 5).

Sample averages reported in this manuscript give the population-weighted average across the 11 high-income countries (or subsamples, where indicated). Reported ranges indicate the minimum and maximum values across our sample countries, not uncertainty as such.

Role of the funding source

There was no funding source for this study.

Results

Only 11 of the 36 assessed high-income countries achieved absolute decoupling of consumption-based CO_2 emissions from GDP between 2013 and 2019. These countries are Australia, Austria, Belgium, Canada, Denmark, France, Germany, Luxembourg, the Netherlands, Sweden, and the UK. However, none of these countries achieved emission reductions that are fast enough for a 50% chance of staying under 1·5°C with minimum equity principles (figure 1). The discrepancy between existing trends and required emission reductions is extremely large.

The 11 high-income countries that achieved absolute decoupling differ in how far they fall short of the required mitigation rates (figure 2). These differences are caused by differences in their achieved mitigation rates (red trend lines), and differences in how fast they need to cut their emissions (dotted green curves) to stay within their respective carbon-budget fair-shares, as they start from substantially different per-capita emissions (appendix pp 19–20). The UK comes closest to what would be required for meeting its 1·5°C fair-share, but still falls markedly short.

A continuation of the 2013–19 average emission reduction rates achieved in the 11 countries through decoupling (business as usual) would not even suffice to reduce their emissions to net zero by 2050, much less to deliver the earlier net-zero dates (on average, in the late 2030s) required for these countries to comply with their 1·5°C fair-shares. On the basis of their 2013–19 decoupling achievements, the 11 countries would take between 73 years and 369 years (223 years, on average) to reduce their respective 2022 emissions by 95%, and would burn between five times and 162 times (on average, 27 times) their respective remaining post-2022 national fair-shares of the global carbon budget for 1·5°C in the process.

The emission reductions achieved via decoupling during 2013–19 are clearly inadequate for high-income countries to deliver on their 1·5°C fair-shares. Furthermore, the disjuncture between achieved and required mitigations rates is very large (figure 3). On average, the 2013–19 decoupling achievements in the 11 high-income countries delivered mitigation rates of 1·6% (range 0·8–4·0) per year. By contrast, the fair-share emissions pathways would on average require mitigation rates of 30% per year by 2025, and 38% per year by 2030. Even the UK would need to accelerate its year-on-year mitigation rate by a factor of five by 2025 and by a factor of seven by 2030 (from its 2013–19 average of 3·1% per year to 16% per year by 2025, and 22% per year by 2030). The other ten countries would all need to accelerate their mitigation rates by more than a factor of ten within the next 4 years, and the lowest-performing countries in our sample (Belgium, Australia, Austria, Canada, and Germany) by more than a factor of 30.

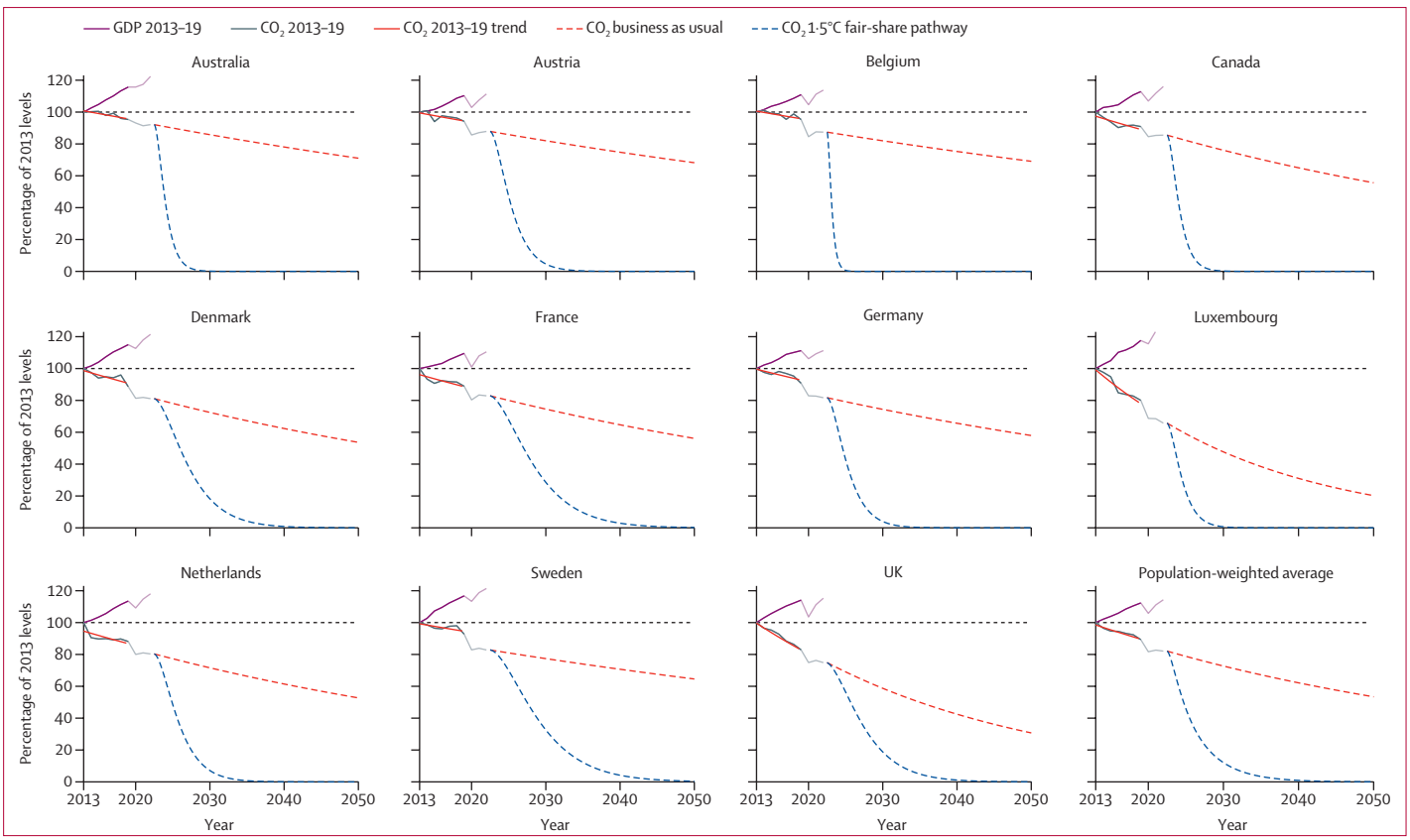

***Figure 2*: In all high-income countries that have recently achieved absolute decoupling, the achieved emission reductions are far from the emission reductions required to comply with their 1·5°C fair-shares**

GDP and consumption-based CO_2 emissions (expressed as percentages of the respective 2013 levels) for the 11 high-income countries that have recently achieved absolute decoupling, and for their population-weighted average (last panel) are shown. For the period 2013–19, GDP is shown in purple, and CO_2 emissions are shown in dark grey, with the 2013–19 emissions trend superimposed in red. For the volatile period since the COVID-19 crisis (2020–22), GDP is shown in light purple, and CO_2 emissions are shown in grey. The dashed red curves show projected emissions for a continuation of 2013–19 average GDP growth rates and decoupling rates (business as usual). The dashed blue curves show emissions pathways that would limit the future emissions of countries to their fair-shares in the remaining global carbon budget for a 50% chance of staying below 1·5°C. GDP=gross domestic product.

To explicitly account for GDP growth rates, we need to consider decoupling rates (ie, year-on-year relative reductions in CO_2 emissions per unit of GDP). The decoupling rates achieved in high-income countries between 2013 and 2019 fall far short of what would be required for these countries to respect their 1·5°C fair-shares while continuing to pursue GDP growth at their 2013–19 average rates. In other words, the achieved decoupling rates are markedly insufficient to meet the requirements for green growth (figure 4).

The UK, which combines relatively low per-capita emissions (6·9 Gt/cap in 2022) with relatively fast 2013–19 decoupling of 5·3% per year, would need to more than triple its decoupling rate by 2025 (to 17·4% per year) and accelerate it by a factor of almost five by 2030 (to 23·9% per year). Sweden, the country with the lowest per-capita emissions (5·8 Gt/cap in 2022) and accordingly, the lowest required mitigation rates in our sample, would need to almost quadruple its decoupling rate by 2025 and accelerate it by more than a factor of five by 2030 (from its 2013–19 average of 3·4% per year to 12·8% by 2025 and 18·6% by 2030). On average, the 11 countries would need to accelerate their decoupling rates by a factor of ten by 2025 and by a factor of 12 by 2030.

The above-mentioned analysis establishes that decoupling achievements in high-income countries are inadequate for 1·5°C fair-shares. We now turn to our sensitivity analysis for 1·7°C fair-shares (reflecting the minimum ambition of the Paris Agreement to limit global warming to "well below 2°C").[23] For this less ambitious (and more dangerous) global climate target, the disjuncture between achieved and required rates of mitigation and decoupling is less extreme, but nevertheless very large in most cases (figure 5). On average, mitigation rates would need to accelerate by more than a factor of eight by 2025, and by a factor of 12 by 2030. Even across the better-performing countries, mitigation rates would need to triple by 2025 (double in the UK) and accelerate by a factor of five by 2030 (by a factor of three in the UK). The required decoupling rates would be more within reach in the best-performing countries, but on average, decoupling rates would still need to almost quadruple by 2025 and accelerate by a factor of five by 2030.

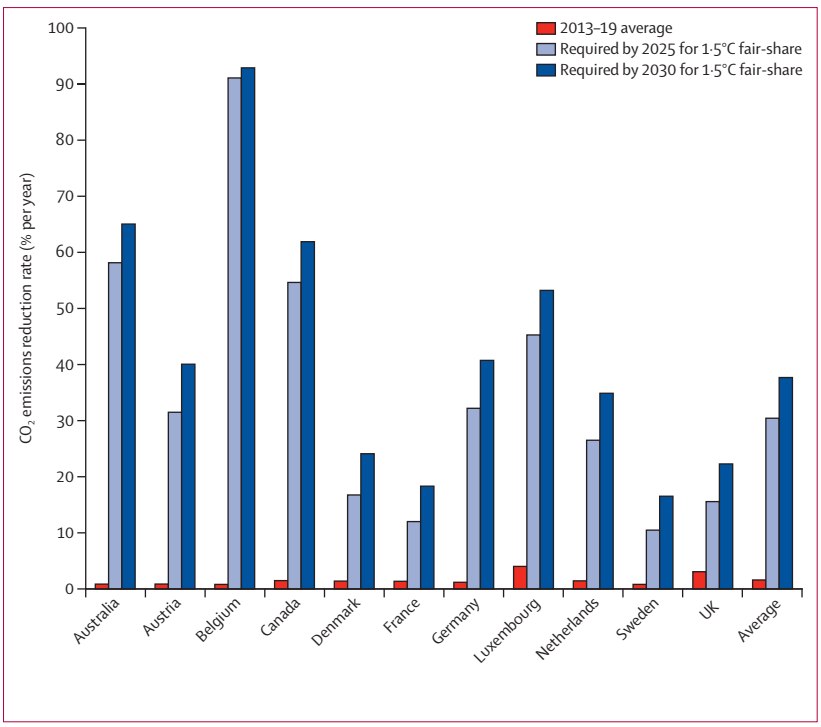

***Figure 3*: The emission reduction rates required for high-income countries to respect their 1·5°C fair-shares (blue) are several times faster than the emission reduction rates they have achieved through recent absolute decoupling (red)**

The red bars indicate 2013–19 average year-on-year emission reduction rates. For the 1·5°C fair-share emissions pathways, the required year-on-year emission reduction rates increase from 2025 (light blue) to 2030 (dark blue), as the emissions pathways (Raupach curves) involve a gradually ramped-up exponential decay rate. The bars labelled "Average" refer to the population-weighted average of the 11 high-income countries.

Discussion

Our results show that the mitigation rates achieved in high-income countries through recent absolute decoupling fall markedly short of the rates required for these countries to remain within their fair-shares of the global carbon budget for a 50% chance of limiting global warming to 1·5°C. The immense increase in decoupling rates that would be required to make continued economic growth in high-income countries compatible with national 1·5°C fair-shares appears to be empirically out of reach, even for the best-performing countries. In most cases, even the decoupling rates required for reconciling continued economic growth with national fair-shares for a 50% chance of 1·7°C (reflecting the lower-end ambition of the Paris Agreement) remain out of reach. Our analysis thus suggests that green growth approaches, understood here as pursuing climate mitigation alongside continued economic growth, are inadequate for high-income countries to deliver on their Paris obligations. Further economic growth in high-income countries is at odds with the climate and equity commitments of the Paris Agreement.

Narratives that celebrate decoupling achievements in high-income countries as green growth are thus misleading and represent a form of greenwashing. At the achieved mitigation rates, these countries will on average take over 220 years to reduce CO_2 emissions by 95% and will exceed their fair-share carbon budgets by more than 27 times in the process. If high-income countries exceed their fair-share carbon budgets, they either exacerbate climate breakdown or appropriate the carbon budget shares of lower-income countries, or most likely they do both. There is nothing green about this. If we are to refer to what is happening in these countries as green growth, then green growth is not adequate for avoiding climate catastrophe, much less for achieving climate justice. Alternatively, if green growth is supposed to be consistent with the climate and equity targets of the Paris Agreement, then green growth has not been achieved in high-income nations, and it appears very unlikely to be achieved in the future.

Our findings are robust to different future population scenarios (high-fertility variant and low-fertility variant)[28,36] and to meaningful variations in the criteria for absolute decoupling of consumption-based CO_2 emissions from GDP. In the assessed period, no high-income (Annex-1) country came closer to achieving the required decoupling rates than the best-performing countries that meet our definition for absolute decoupling (ie, the best cases in our analysis). For many other high-income countries, the required decoupling rates are even further out of reach, and many in fact still increased their emissions between 2013 and 2019. Importantly, falling short of the required mitigation rates in any given year makes it even harder for a country to be on course to meet its fair-share carbon budget, because higher emissions in a given year would require even faster mitigation and decoupling rates subsequently. Our conclusions remain the same when assessing our sample countries on territorial rather than consumption-based emissions, that is to say when ignoring emissions embodied in trade (appendix pp 11–13). For a few countries, the required decoupling rates for 1·5°C and in particular 1·7°C fair-shares would be more within reach, but across all sample countries, by 2025, decoupling rates would on average need to be accelerated by a factor of 13 to comply with 1·5°C fair-shares, and by a factor of five to comply with 1·7°C fair-shares.

Our analysis is conservative in several regards and should thus be seen as a best case for green growth. First, our allocation of the global carbon budget reflects only a minimum interpretation of equity regarding future mitigation. Stronger notions of equity would result in smaller carbon budgets for high-income countries, and thus require even faster mitigation and decoupling rates (appendix pp 8–10). Second, recent estimates[37–39] suggest that the remaining global carbon budgets might be even smaller than the ones used here, which would require even faster mitigation and decoupling rates. Third, we estimate decoupling rates for the business-as-usual and fair-share pathways assuming a continuation of 2013–19 average GDP growth rates, whereas green growth advocates typically aspire to higher growth rates. With higher future growth rates, emission reductions from a continuation of achieved decoupling rates would be

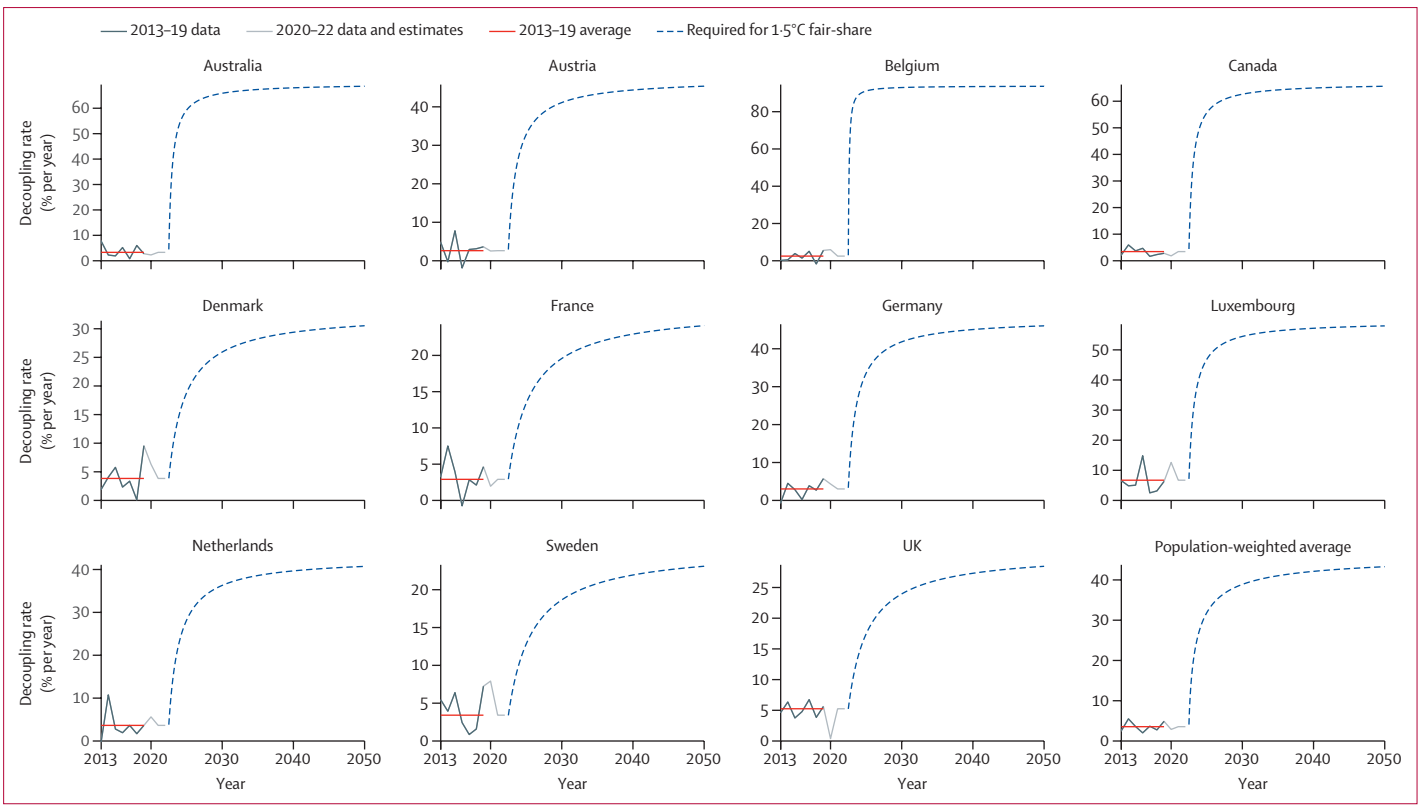

***Figure 4*: The decoupling rates achieved in high-income countries between 2013 and 2019 fall far short of the rates required for green growth**
Decoupling rates (ie, year-on-year percentage reduction rates in CO_2 emissions per unit of gross domestic product [GDP]) for the 11 high-income countries that achieved absolute decoupling between 2013 and 2019, and for their population-weighted average (last panel) are shown. For the period of absolute decoupling (2013–19), decoupling rates are shown in dark grey, with the 2013–19 average rates superimposed in red. For the volatile period since the COVID-19 crisis (2020–22), decoupling rates are shown in light grey. The dashed blue curves show the decoupling rates that would be required for green growth (ie, required for these countries to deliver emission reductions consistent with their fair-shares in the remaining global carbon budget for a 50% chance of limiting global warming to 1·5°C, while continuing to grow their economies at their 2013–19 average GDP growth rates).

even smaller, and even faster decoupling rates would be required to respect fair-share carbon budgets. Fourth, our analysis assumes adequate mitigation beginning in 2023, but this mitigation does not appear to be occurring. This delay and any further delay in decisive mitigation action necessitates even faster mitigation and decoupling rates subsequently, thus moving green growth even further out of reach.

A limitation of our analysis is that the consumption-based CO_2 emissions data used here do not include emissions from agriculture, forestry, and land use, nor emissions from international aviation and shipping (appendix p 14). It is worth noting that adding these emissions would mean that high-income countries would need to reduce their emissions even faster (to meet an even smaller remaining budget from an even higher starting point), and the disjuncture between achieved and required decoupling would be even larger, thus reinforcing our conclusions. Given the robustness of our results, the conservativeness of our methodological choices, and the conservativeness of the limitations, we are confident that our conclusions are robust.

Our findings have important implications for climate mitigation policy in high-income countries. Decoupling can certainly be accelerated. However, there are real physical limits to how much and how fast decoupling can be sped up within a growth-based approach. Under growth-oriented conditions, decoupling (indeed mitigation) relies mainly on replacing existing infrastructure and technology (eg, energy infrastructure and the car fleet) with low-carbon or low-energy alternatives. This type of transition cannot be done at just any desired speed, nor promptly accelerated at any desired rate, given available production facilities, know how, labour, material resources, existing infrastructure, and so on. And slower decoupling rates in the near term would require much faster decoupling rates later to remain within a given carbon budget. The large, near-instantaneous acceleration of decoupling that would be required for high-income countries to achieve green growth is thus very unlikely to be feasible.

Given the limitations of green growth approaches, what can high-income countries do to achieve faster emission reductions? A crucial step is to stop the pursuit of aggregate economic growth and instead pursue post-growth approaches oriented towards sufficiency, equity, and wellbeing.[4,40–42] Post-growth approaches entail equitably reducing carbon or energy intensive and

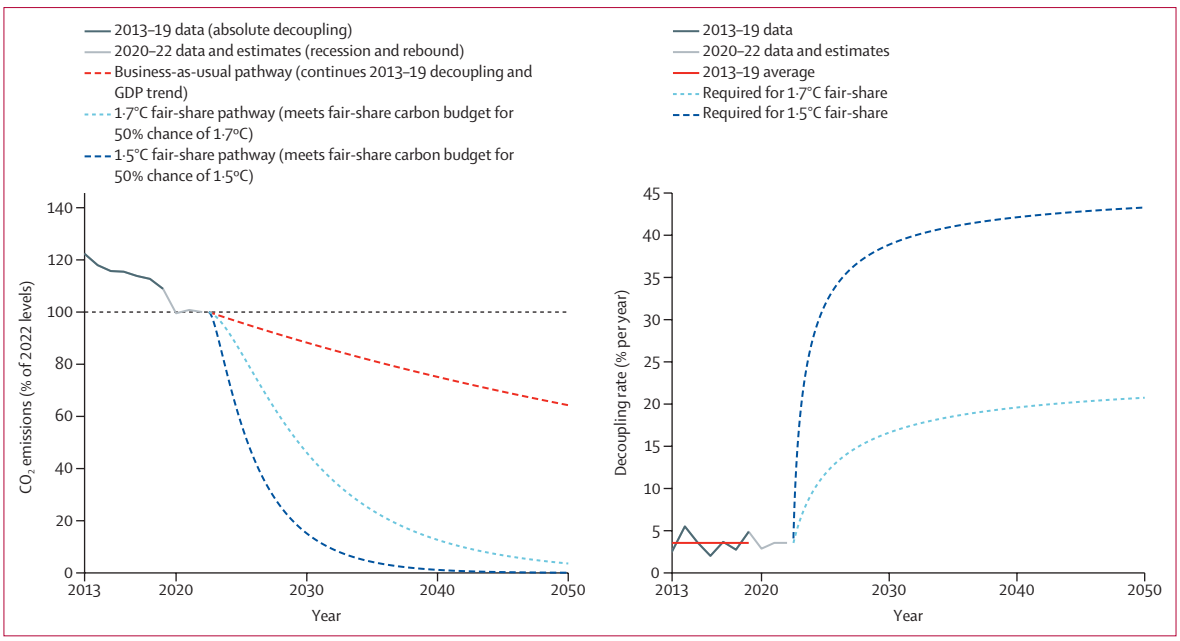

***Figure 5*: Emission reductions (left) and decoupling rates (right) achieved in high-income countries through absolute decoupling are insufficient for complying with their 1·5°C fair-shares or even just with their 1·7°C fair-shares**

Population-weighted averages across the 11 high-income countries that achieved absolute decoupling between 2013 and 2019 are shown. Left panel: consumption-based CO_2 emissions for the 2013–19 absolute decoupling period (dark grey), a business-as-usual continuation of 2013–19 trends (dashed red), and fair-share pathways that meet national fair-shares of the global carbon budgets for a 50% chance of limiting global warming to 1·5°C (dashed dark blue) and 1·7°C (dashed light blue), expressed as percentages of 2022 emissions levels, are shown. Right panel: 2013–19 annual (dark grey) and average (red) decoupling rates versus decoupling rates required for 1·5°C fair-shares (dashed dark blue) and 1·7°C fair-shares (dashed light blue)—ie for reducing emissions in line with emissions pathways that comply with national fair-shares of the global carbon budgets for a 50% chance of limiting global warming to 1·5°C and 1·7°C, respectively, while continuing to grow national gross domestic product at 2013–19 average growth rates are shown.

less-necessary forms of production and consumption,[42–45] improving provisioning systems,[46–50] and shifting to low-carbon, low-energy alternatives for necessary goods and services.[44,45,51,52] These measures reduce aggregate economic activity and decrease total energy demand, thus directly driving down emissions while also enabling faster decarbonisation[3,52–55] (by reducing the amount of renewable energy infrastructure that needs to be deployed overall, and the emissions entailed in the production, installation, and maintenance of that infrastructure;[3] appendix p 6). Rapid renewable-energy deployment and efficiency improvements remain essential and can be accelerated through public finance and regulation. Indeed, post-growth demand-reduction strategies free up productive capacities (factories, labour, materials), which can be redirected to further accelerate decarbonisation efforts, with public works and a job guarantee.

In decoupling terms, the measures described here substantially and rapidly reduce the overall carbon intensity of the economy, and thus accelerate decoupling beyond what can be achieved in a growth-oriented scenario through replacement of infrastructure and technology.

The latest IPCC report[56] and recent studies highlight the huge and thus far largely untapped mitigation potential of demand-reduction strategies, with an emphasis on sufficiency, equity, wellbeing, and improvements to provisioning systems.[44–46,51–55] Policy makers can take several steps toward this end: shifting away from economic growth as a core objective, and instead prioritising equity, human wellbeing, and ecological sustainability;[40,41,57–59] scaling down energy-intensive or carbon-intensive and less-necessary forms of production and consumption (eg, sports utility vehicles, air travel, industrial meat and dairy, fast fashion, weapons, cruises, mansions, and private jets);[43–45,51] reducing income and wealth inequality, and curtailing the purchasing power and consumption of wealthy classes (eg, via wealth taxes and maximum income thresholds);[54,60–62] insulating buildings and repurposing buildings to minimise new builds;[42,51,52,63] reducing food waste, and shifting to agroecological farming techniques and predominantly plant-based diets;[51,64–66] introducing laws to end planned obsolescence, lengthen product lifespans, and guarantee rights to repair;[42,51,67] shifting away from private cars while also improving public transit, bike systems, and walkability;[42,51,68] and shifting from commodified for-profit provisioning to decommodified, socially and ecologically beneficial not-for-profit provisioning.[69,70] Livelihoods and wellbeing can be secured independently of economic growth,[71] by shortening and redistributing working hours to secure employment,[72] introducing a public job guarantee,[73] living wages, living pensions,[74] and a minimum income guarantee,[75] and providing universal access to affordable housing and good-quality public services.[76,77]

Model studies suggest that such strategies, with equitable and sufficiency-oriented demand reduction in high-income countries and international convergence in per-capita consumption levels, could decrease global emissions fast enough to limit warming to 1·5°C.[4,42,55] A sufficiency-based climate mitigation scenario could cut total energy demand across 30 European countries by 55% by 2050 (around half due to sufficiency measures alone), and limit their combined cumulative CO_2 emissions to their combined fair-share carbon budget for 50% chance of 1·5°C.[53] Similar demand-reduction scenarios have been put forward for the UK,[52] France,[78] and Germany.[79] In these scenarios, these countries get close to meeting their 1·5°C fair-shares (as defined in this study), but effectively still fall short, because they do not account for the often substantial net-imported emissions of these countries, and assume transformative mitigation has already begun. Fortunately, there is still scope for further ambition and speed.[44–46,54] However, countries with very high per-capita emissions (such as Belgium, the USA, or Saudi Arabia) have already depleted most of their carbon budget fair-shares since 2020. For those countries, ambitious demand-reduction policies are all the more imperative, but even that might not reduce their emissions fast enough to prevent them from exceeding their remaining carbon budget fair-shares, and thus from either appropriating the fair-shares of other (poorer) countries, or exacerbating climate breakdown. In these cases, compensation and reparations should be paid.[80]

Debates about green growth relate to high-income countries. Lower-income countries typically have much lower emissions per capita, which makes the mitigation and decoupling rates required for them to stay within their fair-share carbon budgets more modest and therefore more achievable. Countries such as Uruguay and Mexico are already making strides in this direction.[81] With adequate access to the necessary finance and technology, freedom to use industrial policy, and a development strategy focused on human needs, lower-income countries should be able to stay within their fair-share carbon budgets even while increasing production and consumption to achieve decent living standards for all. Indeed, post-growth transitions in high-income countries are crucial for enabling and creating space for sovereign development in lower-income countries.

It is worth noting that virtually all dominant climate-mitigation scenarios involve continued economic growth in high-income countries. The problems created by this approach are concealed in these scenarios by relying on unrealistic assumptions about decoupling and energy efficiency,[4,72,83] unrealistic assumptions about the rollout rate of renewable energy,[4] unrealistic and risky assumptions about future negative-emission technologies,[32–35] highly unequal international burden sharing (future cumulative emissions per capita), and undermining energy use and development in low-income and middle-income countries.[84] Post-growth approaches would enable societies to largely avoid these problems, thus improving technological feasibility as well as international and intergenerational equity.

We want to emphasise that post-growth climate-mitigation scenarios cannot be modelled by assuming some decoupling rate and simply reducing GDP. Indeed, post-growth scholarship explicitly rejects the idea of reducing GDP as a lever for climate mitigation, focusing instead on specific sufficiency and efficiency policies (as described above), along with public investment to accelerate decarbonisation. Crucially, post-growth proposals do not seek to reduce all production and consumption, but primarily carbon or energy intensive and less-necessary forms of production and consumption, while also increasing necessary forms of provisioning as needed. Whereas the energy and emissions impacts of key post-growth climate-mitigation policies have been modelled,[52,53,78] what would happen to GDP in a post-growth scenario depends on various factors, including what sectors are reduced or expanded, how provisioning systems and income distributions are transformed, to what extent provisioning gets decommodified, to what extent currently unpaid work or production gets remunerated, and what happens to prices. Clearly, changes in GDP cannot be simply deduced from an assumed emissions pathway and decoupling rate (see the Methods section). It is quite possible that GDP could decline in a post-growth scenario, but post-growth labour and welfare policy can secure livelihoods and improve wellbeing independently of what happens to GDP.[71]

Climate-mitigation policy should not be seen in isolation but in the context of the broader ecological crisis. The global economy is also transgressing six other planetary boundaries,[85] and high-income countries are overwhelmingly responsible for this.[86] We have focused on emissions here, but ultimately the benchmark for green growth is whether it can limit not only emissions but also other environmental impacts to national fair-shares of planetary boundaries.[5] Future research should involve a similar analysis of national performance on these other planetary boundaries. We know that ecosystem damage and biodiversity loss are closely related to material use, which is being driven in large part by economic growth.[87,88] Indeed, there is little evidence that high-income countries are achieving sufficient absolute decoupling of GDP from material footprint.[8] Here, too, post-growth demand reduction and sufficiency strategies are urgently needed to complement and accelerate feasible technological changes and efficiency improvements.[8,89,90]

Overall, our analysis suggests that if high-income countries are to reduce emissions in line with the Paris Agreement, they will need to abandon the pursuit of aggregate economic growth and instead adopt equitable and sufficiency-oriented post-growth policies. The evidence is clear. Society must act quickly or "will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all".[91]

Contributors
JH conceived the study. JV led the design of the methods, curated the data, did the computations, and produced the visualisations. JV and JH accessed and verified the data, interpreted the results, wrote the original draft, and made revisions and edits. JH supervised the work. Both authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Declaration of interests
We declare no competing interests.

Data sharing
The source data used for this study are publicly available from the Global Carbon Project, the World Bank, the Organisation for Economic Co-operation and Development, and the United Nations Population Division. The results data will be made available upon reasonable request to the corresponding author.

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