# *Greening prosperity stripes across the globe*

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Methodological and Ideological Options

# Greening prosperity stripes across the globe☆

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ABSTRACT

This paper is motivated by the urgency of climate change mitigation and the crucial importance of communicating the need for it. Our approach relies on using comparative visualizations in terms of maps and stripes in color for all countries across the globe that can easily be conveyed and understood even by nonspecialists. It proposes an intuitive novel measure of what we refer to as 'greening prosperity stripes', defined to be visually comparable across countries over time along a brown-to-green pallette depicting the ratio of real gross domestic product (GDP) per capita to carbon dioxide (CO2) emissions per capita, based on annual data from the World Bank since 1990. We illustrate our findings along both cross-section and time-series dimensions, acknowledging that images and colors speak louder than words and affect emotionally, thereby hoping to raise awareness and mobilize immediate climate policy action worldwide. Moreover, the greening prosperity world maps and stripes by country, possibly updated online every year, can be used to track progress toward the goal of net zero clearly and compellingly.

## 1. Introduction

As is by now well documented, 2023 and then 2024 were the warmest years on record. The longest publicly available average temperature data at annual frequency for the world as a whole we are aware of can be accessed online via the UK Government's Met Office Hadley Centre for Climate Science and Services. These data cover the period 1850–2023 (174 years) and are plotted in Fig. 1.

The data in the top panel show the evolution of average world temperature in degrees Celsius (that is, northern and southern hemisphere of the globe equally weighted) every year since 1850. In representing the data on this figure, we have followed the convention in meteorology to depict what they call 'temperature anomalies', i.e., deviation of annual temperatures from what we usually denote in economics as a long-run 'steady state', and a recent one: that is, the deviation of the average temperature each year since 1850 from the mean for the period 1960–1990. What strikes on the top-panel graph is the change in trend evident since the early 1980s, when the world has added by 2016 nearly 1 degree C on top of the mean for 1960–1990. Earlier, for about more than a century of recorded data, world average temperatures have fluctuated without any long-lasting trend.

The histogram in the bottom panel of Fig. 1 presents the same data, but changing the perspective from a time-series representation into a probabilistic one. It shows the empirical probability density of these temperature anomalies relative to the mean for 1960–1990. One can easily observe the long and relatively thin upper (or right) tail of this distribution, depicting these anomalies that have been corresponding to the period since 1980 in the top-panel graph of the same figure.

Against this background, and linking rising world temperatures with macroeconomic data, the present work proposes a basic concept, namely, a 'greening prosperity' indicator, as well as its measurement and visualization, employing intuitive panels of graphs in color that provide various comparative perspectives. It is motivated by the urgency of climate change mitigation and the crucial importance of

☆ A much more detailed discussion paper version, Mihailov (2023), was issued online at the Department of Economics of the University of Reading in November 2023, and was revised in April and again in September 2024. A dense policy column, Mihailov (2024), was published online at *Economics Observatory*. I warmly thank the Editor, Heinz Schandl, and three anonymous referees of this journal for very helpful feedback that allowed me to restructure and sharpen the final write-up following three revisions. I am also grateful to seminar participants at the University of Reading (July 2023, GEAR Retreat), the 3rd Lille-Reading Workshop on International Finance (October 2023, Reading), the 8th European Workshop on Political Macroeconomics (June 2024, Sofia), the 55th Money, Macro and Finance Society annual conference (September 2024, Manchester), and the Climate and Finance conference (September 2024, ICMA/HBS – Reading), in particular Mark Casson, Laura Coroneo, Florence Huart, James Reade, Jamel Sadaoui, Carl Singleton and Cédric Tille for constructive comments, as well as Wendy Carlin, Ed Hawkins and George Mengov for useful discussion of the project as it was progressing. Any remaining errors or misinterpretations are my own responsibility.

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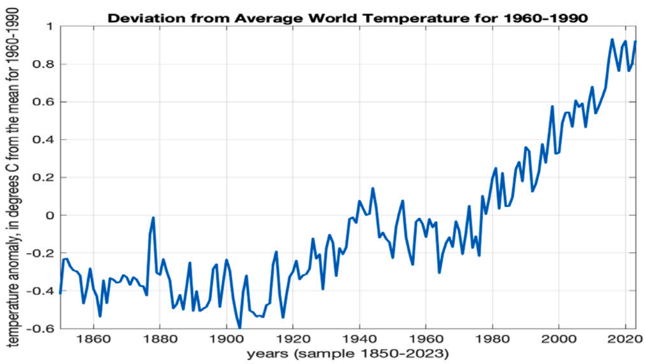


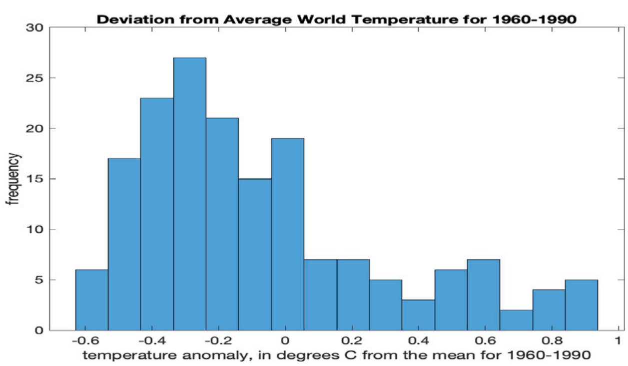


**Fig. 1.** Global annual temperature 'anomalies' since 1850.
*Note*: The top panel provides a time-series view, while the bottom panel complements it by a frequency dimension for the same data.
*Source:* UK Government's Met Office Hadley Centre for Climate Science and Services, https://www.metoffice.gov.uk/hadobs/hadcrut5/data/current/download.html.

explaining clearly the need for it. The proposed new indicator can readily be used to track progress by country along the goal of net zero greenhouse gas (GHG) emissions in the near future. Our approach focuses on versions of a comparative visualization in color of world maps (in a cross-sectional view) and country or country-grouping stripes (in a time-series perspective) of real gross domestic product (GDP) per capita (pc), carbon dioxide (CO2) emissions pc and the resulting greening prosperity ratio (GPR), measured in constant United States dollars (USD) of 2017 at purchasing-power parity (PPP) exchange rates per metric ton of CO2 emissions (i.e., dividing the real GDP pc indicator by the CO2 emissions pc indicator) for all countries across the globe. Apart from its simplicity, the main advantage of our GPR is that color maps and stripes can easily be conveyed, compared by country or groups of countries and understood quickly even by nonspecialists. The annual panel data we rely on are available online from the World Bank since 1990 for nearly all countries.

The rest of the paper is organized as follows. Section 2 provides an overview of the key related literature in economics. Section 3 defines formally the theory and measurement issues related to the new macroeconomic indicator we propose. Section 4 presents our main results in terms of insightful and comparable across countries colormaps, in a cross-section for the world in 1990 and 2020 as well as for major economies over the years from 1990 through 2020, also suggesting interpretations and highlighting two special cases: Switzerland and the world on average. Section 5, then, discusses the immediate policy implications of our work, and Section 6 concludes, also summarizing some limitations of our greening prosperity indicator to be addressed by future refinements. A supplementary online appendix presents additional comparative colormap stripes for a larger sample of countries.[1]

## 2. Literature

There is a substantial literature, at least since the early 1990s, on the relationship between economic growth, or – less so – life expectancy, and CO2 emissions, or – less so – GHG emissions. But not a single paper has ever linked real GDP pc, approximating social welfare, and CO2 emissions pc, approximating environmental pollution, in a ratio by country expressed in visually comparable colors, as we do in what follows. Our aim was to define an intuitive representation of the mentioned ratio that could serve as a widely accepted indicator of 'greening prosperity' and thereby measure progress toward the goal of net zero. This is exactly the gap in the literature our current paper fills in. In this section, we briefly highlight key approaches and findings in a selection of studies related to ours, mostly to set up the background for analyzing and interpreting our comprehensive comparative visualizations later on.

It may seem a bit surprising to the younger generations, but the scientific literature on the so-called 'greenhouse effect' is about two centuries old. Dobes et al. (2014) trace down its origins to Fourier (1827/2013) and Tyndall (1861), while in economics Arrhenius (1896) was the first to raise the issue about the effect of anthropogenic carbon emissions on the global climate. The same authors divide and survey the subsequent literature in economics into three strands: (i) on trends in climate change, the oldest chronologically – e.g., Keeling et al. (1976) measured the concentration of atmospheric CO2 at Mauna Loa Observatory, Hawaii, to document the effects of the combustion of coal, petroleum, and natural gas on the distribution of CO2 in the atmosphere, finding that the annual average CO2 concentration rose by 3.4% between 1959 and 1971; (ii) on mitigation of climate change, with the field of environmental economics gaining more visibility following the first oil price shock in the 1970s, e.g., d'Arge et al. (1982), Edmonds and Reilly (1983a,b); and (iii) on adaptation to climate change, with the policy concerns regarding urgent global action becoming more and more acute since the late 1980s and the early 1990s, e.g., the dynamic integrated climate economy (DICE) models and the regional integrated climate economy (RICE) models of Nordhaus (1993) and Nordhaus and Yang (1996), as well as, more recently, Stern (2008) and many studies that followed.

Perhaps the earliest formalized awareness of the concern about limited and exhaustible natural resources was proposed in the seminal paper by Hotelling (1931). Devarajan and Fisher (1981) revisit Hotelling's contribution on the occasion of its 50th anniversary and write that "Hotelling had a two-fold purpose in writing the 1931 paper: (1) to assess the policy debates arising out of the conservation movement and (2) to develop a theory of natural resources" (p. 66). According to these authors, a second wave in the literature on exhaustible resources spurred in the 1970s. Then in the 1990s (Grossman and Krueger, 1991, 1993, 1995) put the beginning of a third wave in this literature, defining the environmental Kuznets curve (EKC), first in their 1991 NBER working paper, by analogy with the work of Kuznets (1955) relating economic growth to income inequality (see also Acemoglu and Robinson (2002) on the political economy of the original Kuznets curve). According to the EKC hypothesis, as also claimed in the survey by Dinda (2004), p. 431 (abstract), there exists "an inverted-U-shaped relationship between different pollutants and per capita income, i.e., environmental pressure increases up to a certain level as income goes up; after that, it decreases". Dinda (2004) provides

[1] Much further detail and variations of the colormaps can be found in the discussion paper version of this article, Mihailov (2023), and its dense policy-column version, Mihailov (2024).

an overview of the EKC literature, its history, insights, policy as well as its conceptual and methodological critiques, and summarizes this literature (up to 2004) in the sense that “evidence for the existence of EKC is inconclusive”. (p. 450).

Brock and Taylor (2005) write in their book chapter abstract that “[t]he relationship between economic growth and the environment is, and will always remain, controversial”. Their review article discusses and evaluates the theoretical literature linking environmental quality to economic growth, focusing on three questions: “(1) what is the relationship between economic growth and the environment? (2) how can we escape the limits to growth imposed by environmental constraints? and (3) where should future research focus its efforts?”. They claim to have identified major unresolved theoretical questions and to have presented the results of recent empirical work (up to 2005).

Bengochea-Morancho et al. (2001) study the relationship between economic growth and CO2 emissions in the European Union (EU). They employ a panel data analysis for 1981–1995 to estimate the relationship between GDP growth and CO2 emissions in 10 EU countries. Their results do not support a uniform policy to control emissions, but indicate instead that a reduction in emissions should be achieved by taking into account the specific economic situation and the industrial structure of each EU member state. However, Alaganthiran and Anaba (2022) claim to have established that a 1% increase in economic growth in a sample of 20 Sub-Saharan African countries increases CO2 emissions by approximately 0.02%.

Alternative measures of environmental inequality in the 50 US states, differentiated by their exposure to industrial air pollution, are examined by Boyce et al. (2016). They find substantive differences in rankings by different measures and conclude that no single indicator is sufficient for addressing the entire range of equity concerns that are relevant to environmental policy; instead multiple measures are needed.

As far as life expectancy is concerned, as another common indicator of well-being to replace or complement GDP pc, Das and Debanth (2023) note that life expectancy has a probable connection with CO2 emission in two opposite ways: (i) more CO2 emissions lead to more production of output and higher income level, which is likely to affect the life expectancy of people in a positive way; (ii) conversely, CO2 emissions are an important air pollutant and may reduce the span of human life. Their paper aims to investigate the net impact of CO2 on life expectancy in India. The main finding is that India has already surpassed its optimal atmospheric concentration of CO2 and thereby should adopt CO2 reduction strategies.

Employing a new dataset on comparable global CO2 production and consumption inventories over 1997–2011, Fernández-Amador et al. (2017) study the relationship between real GDP pc and CO2 emissions pc associated with both production and consumption activities. They claim to have focused on the entire carbon chain, which includes linkages between production-based emissions in one country and final consumption in another, via cross-border value chains. By estimating polynomial and threshold models that account for problems of reverse causality and identification, they find that the income elasticity for both inventories is regime-dependent and reflects small carbon efficiency gains from economic development.

With regard to a related issue, namely, income inequality, Grunewald et al. (2017) report empirical findings according to which for low- and lower middle-income economies higher income inequality is associated with lower per capita CO2 emissions, while in upper middle-income and high-income economies higher income inequality increases per capita CO2 emissions. Their results, thus, do not support an EKC related to income inequality. By contrast, the empirical findings in Santillán-Salgado et al. (2020) suggest a validation of the EKC, measured by CO2 emissions per capita and GDP per capita. Moreover, they argue that CO2 emissions have a long-term relationship with economic growth, energy use, electricity use, urbanization, and inequality. Yet, according to the same study, in a short run CO2 emissions depend mostly on a subset of the mentioned factors, namely, economic growth, urbanization, and income inequality.

Schandl et al. (2016) point to the widely discussed ‘decoupling’ between economic growth and CO2 emissions, i.e., whether it is possible for an economy to grow without increasing CO2 emissions. This appears opposite to the typical trend for the 20th century that economic growth and human well-being around the globe have come at the cost of fast-growing natural resource use and carbon emissions. These authors ask whether well-designed policies can reduce global material and energy use, and carbon emissions, with only minimal impacts on improvements in living standards. Employing a novel approach of combined economic and environmental modeling, they evaluate the potential for decoupling for 13 world regions and globally. A production (territorial) approach as well as a consumption approach are applied to discuss regional differences in natural resource use and carbon emissions across three stylized policy outlooks. Schandl et al. (2016) find that “OECD economies have significant potential to reduce their material throughput and carbon emissions with little impact on economic growth, and that developing economies such as China could expand their economies at much lower environmental cost”. They also conclude that, at a global scale, “the effects of very strong abatement and resource efficiency policies on economic growth and employment until 2050 are negligible”.

On the same topic of decoupling, Ritchie (2021) argues that it has been evidenced in the data for the UK. However, she notes that UK CO2 emissions peaked in 1972, but this does not consider imported emissions — such as arising from UK import products that are manufactured abroad. If these imported emissions are taken into account, then UK emissions have peaked in 2007. Ritchie (2021) also claims that the biggest source of these ‘imported’ emissions is China, followed by the EU. Emissions produced directly by the UK have declined, notably due to “a combination of environmental policies and a shift of the UK economy from more carbon-intensive manufacturing to less carbon-intensive service-based industries”. She presents estimates according to which when looking at the UK’s CO2 emission intensity, which continues to fall, the energy generation (negative 67%), manufacturing (negative 43%), water supply (negative 38%), and transport (negative 33%) sectors saw the biggest falls between 1990 and 2017. The change from coal to renewable energy, as well as offshoring of polluting industries, has further contributed to UK CO2 emissions continued decrease.

## 3. Methodology and data

Similarly to the resource and environmental economics literature just outlined, the measurement and theory of macroeconomic indicators and price and quantity indexes is now more than a century old too: see, e.g., Mitchell (1913), Fisher (1921), Kuznets (1934), Leontief (1936), Burns and Mitchell (1946), Koopmans (1947) and Kaldor (1961). Our aim here is not to provide a survey of its rich and well-known history of contributions, but rather to focus directly on designing a visual indicator that captures economic prosperity relative to CO2 emissions as gradually ‘greening’ (or ‘browning’) over time — for the world as an average as well as for each country and major country grouping.

### 3.1. Theory

Mathematically, we aim at an indicator that is some function of variables changing over time $y_t(\ldots)$. The arguments of the function may potentially be several, and the functional forms may potentially be several too. The simplest and most obvious approach we pursue hereafter is to impose a general function of two arguments $y_t(x_t, z_t)$, where $x_t$ is some measure of economic prosperity and $z_t$ is some measure of the degree of environmental pollution, and the respective partial derivatives are as follows:

$$\frac{\partial y_t(x_t, z_t)}{\partial x_t} > 0 \text{ and } \frac{\partial y_t(x_t, z_t)}{\partial z_t} < 0 \tag{1}$$

The specific functional form satisfying the above conditions can be, in its simplest expression, just a ratio

$$y_t(x_t, z_t) = \frac{x_t}{z_t} \tag{2}$$

where $x_t$, some measure of prosperity in real value per capita, will tend to grow over time, while $z_t$, some measure of environmental pollution in real value per capita, will tend to decrease over time, reaching a minimum of a unit, the latter defined as virtually zero pollution. So, as $z_t \to 1$, $y_t \to x_t$, with the limit defining completely green – i.e., unpolluted, clean or 'undiscounted' (by emissions) – prosperity in real value per capita.

To translate the above prosperity indicator discounted by the degree of emissions into a colormap stripes image, one needs to define a function capturing the global minimum and the global maximum in a dataset, represented as a matrix $\mathbf{M}$, ideally a balanced panel of countries (and country groups) as rows, $\mathbf{M_j}$, of the matrix, $j = 1, 2, \dots, J-1, J$, and years as columns of the matrix, $\mathbf{M_t}$, $t = 1, 2, \dots, T-1, T$. Then each element of the matrix, $m_{jt}$, is a country-year observation, each row of the matrix, $\mathbf{M_j}$, is a country $j$ evolving over time, and each column of the matrix, $\mathbf{M_t}$, is a cross section in year $t$. Now there are two straightforward ways to define the stripes, depending on their desired number $n = 1, 2, \dots, N-1, N$ in a colormap image.

One can determine the range, $R$, between the *global* maximum, $Max(m_{jt})$, and the *global* minimum, $Min(m_{jt})$, in the dataset matrix $\mathbf{M}$ as

$$R \equiv Max(m_{jt}) - Min(m_{jt}), \text{ for all } j = 1, \dots, J \text{ and all } t = 1, \dots, T \tag{3}$$

as we do in our preferred visualization of the proposed colormap stripes by countries over time to ensure direct comparability (illustrated further down in the present paper), and then allocate to it the respective number of desired colors (and nuances) as *stripe* $S$ (we chose $N = 16$)

$$S \equiv \frac{R}{N} \tag{4}$$

Alternatively, one can wish instead to focus on a *particular country* stripes $s$ as they are evolving over time, and the respective definitions then involve the particular country vector only in defining the *country* (or *local*) maximum, $\max(m_j)$, and minimum, $\min(m_j)$, range $r_j$, and stripe $s_j$

$$r_j \equiv \max(m_j) - \min(m_j), \text{ for a given } j \text{ and } t = 1, \dots, T \qquad \text{and} \tag{5}$$

$$s_j \equiv \frac{r_j}{N} \tag{6}$$

The above is a *time-series* stripe representation or visualization, i.e., for a country $j$ over time – but such colors are not comparable across countries. Another perspective can present the *cross-section* stripe visualization in a plot of sequences of stripes or on the world map, i.e., for all countries in a given year $t$, with respectively defined variables $\max(m_t)$, $\min(m_t)$, $r_t$, and $s_t$ – but such colors are not comparable across years.

$$r_t \equiv \max(m_t) - \min(m_t), \text{ for a given } t \text{ and } j = 1, \dots, J \qquad \text{and} \tag{7}$$

$$s_t \equiv \frac{r_t}{N} \tag{8}$$

The colormap stripe definitions suggested here above can each be winsorized in several ways, and we exploit one such winsorization, at 5% and 95% for the last year in our panel, 2020, to allow sharper comparison and enhance visibility by allowing the display of more colors within the chosen palette (as will be discussed and illustrated in Figs. 2 and 3 further down).

### 3.2. Measurement

We now define our indicator of 'greening prosperity' more precisely, that is, with view of the available – and comparable across countries – data. One possible, still general, definition consistent with Eq. (2) could be

$$G_{Yt} \equiv \frac{Y_t}{E_t} \tag{9}$$

where $G_{Yt}$ is some measure of 'greening prosperity', defined as $Y_t$, which is some measure of well-being or welfare per capita, relative to $E_t$, which is some measure of emissions in the environment per capita. For both the numerator and the denominator in the above ratio there seem to be at least two obvious candidates. For the numerator, one could use either real GDP pc (comparable internationally) or life expectancy at birth (comparable internationally). For the denominator, one could use a general measure of emissions, such as caused by GHG, which are several,[2] or the largest share of these GHG, which belongs convincingly (as the numbers just mentioned in the footnote indicate) to CO2 emissions. Accordingly, the still general definition in Eq. (9) may specialize as:

$$GPB_{Yt} \equiv \frac{RGDPpc_t}{GHGEpc_t} \tag{10}$$

where $GPB_{Yt}$ is greening prosperity defined *broadly* in terms of real GDP pc, $RGDPpc_t$, 'discounted' (or 'deflated') by (or 'corrected' for or 'cleaned' from) GHG emissions pc, $GHGEpc_t$; or:

$$GPN_{Yt} \equiv \frac{RGDPpc_t}{CO2Epc_t} \tag{11}$$

where $GPN_{Yt}$ is greening prosperity defined *narrowly* in terms, again, of real GDP pc, $RGDPpc_t$, but now divided by CO2 emissions pc, $CO2Epc_t$. An alternative definition of welfare and the related greening prosperity indicator may use the same two versions of the denominator, as in Eqs. (10) and (11), but with a different measure in the numerator, e.g., life expectancy at birth.

To not dilute too much our visualizations and interpretations in this first pass of the proposed greening prosperity stripes in the present paper, we choose hereafter to focus on the – measurement or empirical – definition in Eq. (11). This is also because the data for CO2 emissions are more widely available for all countries in the world than the corresponding, and more encompassing, GHG emissions. We, nevertheless, keep in mind the alternative definitions in the equations above for future exploration.[3]

One advantage of our choice to define greening prosperity as in Eq. (11) is that it is thereby measured in a way allowing for an intuitive interpretation, namely, real GDP pc (in constant PPP international USD) 'discounted' by the degree of CO2 emissions (in metric tons).[4] To define the goal of 'net zero', the metric tons in the typical measure of CO2 emissions could be expressed as kilograms – or even grams – and the minimum defined at unity: the net zero greening prosperity ratio, then, has a denominator of 1 and, thus, does not discount anymore the value of real GDP pc.

[2] The Kyoto Protocol to curb GHG emissions, signed by 39 developed economies in 1997, covered carbon dioxide, accounting for 82% of total anthropogenic GHG emissions from developed countries in 1995, according to UNEP (1999/revised 2002), methane (with 12%), nitrous oxide (with 4%), hydro-fluorocarbons, perfluorocarbons and sulphur hexafluoride, as cited in, e.g., Bengochea-Morancho et al. (2001), p. 165, and updated online at UNEP (1999/revised 2002): https://www.unep.org/resources/report/climate-change-information-kit.

[3] Other obvious proxies for the numerator we could propose are Gross National Income (GNI) pc or real consumption pc, but long time series with international comparability seem harder to find on these.

[4] Note that in the environmental literature such a definition is often denoted as the carbon intensity of output of a country.

### 3.3. Data

Figure 9 in the online appendix presents the World Bank list of all 217 countries in the world, plus 49 country groupings or regions (with their number of ordering, name and country/group code), which we could potentially use hereafter in a comprehensive comparative visualization. The World Bank provides a highly comparable time series of real GDP pc in international constant US dollars of 2017 for (nearly) all countries in the world and applying the methodology of purchasing-power parity (PPP) exchange-rate conversion at annual frequency since 1990. To ensure better precision and comparability, we employ exactly this PPP-USD World Bank time series.

Before going into further disaggregation by country, we here provide some more general discussion based on Table 1. This table lists statistical information with regard to the world as a whole and its four major constituent subgroups, according to the classification by the World Bank. Starting with the world as a whole, one sees that the mean and median GDP pc at PPP in international USD of 2017 have been close together around the value of 12,550 as an average over the 31 years spanning our time period of analysis, 1990–2020. The world has also emitted, on average for the same period, CO2 of some 4.3 metric tons pc (again, the mean and median are pretty close). Consequently, the average greening prosperity ratio for the world during the same period stands at about 2900 'discounted' PPP-USD of 2017. One can, therefore, infer that CO2 emissions pc (as denominator in the ratio) have reduced GDP pc (numerator) by more than 4 times.

Turning to the four major country groups comprising the world, one first notices their significant differences in mean or median GDP pc, going from an average of 41,000–42,000 PPP-USD of 2017 pc for the high-income countries to more than 4 times less for the upper middle-income countries, to nearly 10 times less for the lower middle-income countries and to almost 30 times less for the low-income countries. We observe, therefore, a wide disparity of GDP pc that will affect the numerator of our greening prosperity ratio across these groups of countries.

In terms of CO2 emissions pc, the averaged data in Table 1 do not support the environmental Kuznets curve we introduced earlier: namely, the levels of CO2 emissions pc do not imply an inverted U-shaped relationship between income pc (or GDP pc, here) and the level of economic development, captured by the four major groups of countries in the World Bank classification we use. It is clear that the low-income countries are the lowest CO2 emitters pc, with 0.4 metric tons on average for 1990–2020 (mean and median are almost identical). Lower middle-income countries come next, with CO2 emissions pc of the order of 1.25 metric tons (with close mean and median, but less so), while the upper middle-income countries emit CO2 pc that is nearly four times higher than the emissions of the lower middle-income group and more than 10 times higher than the emissions of the low-income group. Finally, the high-income countries emit the highest level of CO2 pc, with some 11 metric tons (close mean and median, again), i.e., about 2 times and a half more than the mean or median emissions of the upper middle-income group and almost 30 times more than the emissions of the low-income countries. Again, now in the denominator of the greening prosperity ratio we propose here, one observes a huge diversity in the average volume of CO2 emissions pc over the 1990–2020 period across the four major groups of countries that the World Bank defines and examines in typical comparisons.

However, because the two lower-income groups of countries emit CO2 pc much less than the two higher-income groups, we observe a corresponding 'correction' in the greening prosperity indicators that are measured in PPP-USD of 2017 'discounted' by the level of CO2 emissions. This leads to some unsurprising pattern of clustering – but definitely not complete equalization – of the average greening prosperity ratios of the four group of countries, in the range of 2200 USD of 2017 (lowest, for the upper middle-income countries) to some 3700 USD of 2107 (highest, for the high-income countries), and with both the lower middle-income countries and the low-income countries coming very close to the high-income countries (indeed, according to the mean value, and not the median, the low-income countries even somewhat overtake the high-income countries).

## 4. Results

### 4.1. World colormaps in the cross-section of all countries, 1990 and 2020

To begin the analysis of our results,[5] illustrating the value of our approach of color visualizations we promote with this paper, let us compare our three main indicators, as defined in terms of respective color-palette ranges for all countries on the world map, in the first year of our World Bank sample, 1990, in Fig. 2, as well as in the last year, 2020, in Fig. 3. Our interest is, of course, in the novel greening prosperity comparison across countries in the respective bottom panels of these figures. But to be able to also infer whether the numerator (real GDP pc) or the denominator (emissions of CO2 pc) matters more in driving the greening prosperity ratio, we also present their respective color variations on the world map in the top and middle panels of the same two figures.

The top panel in each of the figures shows 16 dark-blue-to-dark-red color patterns, defined by the winsorized minimum at 5% and maximum at 95% in the 2020 data for the respective cross sections in 1990 and 2020 that depict the variation of real GDP pc for all individual countries in the World Bank dataset (listed in Table 9 in the appendix) as plotted on the map of the world. Our purpose of providing the winsorized rather than raw version of these world maps expressing in color our three indicators is to enhance the visibility of, and hence facilitate, the comparisons across countries and regions, where more colors within the palette appear on each continent. Yet, because winsorizing also has the effect of packing together the outliers below and above the chosen thresholds, assigning to them the top and bottom color nuances in our color-palette scales, we mention in the analysis that follows in the main text more precise values regarding the top-ranked and bottom-ranked countries by each of the three examined indicators.

#### 4.1.1. Real GDP per capita

In 1990 on Fig. 2, the United Arab Emirates (UAE) comes far ahead on top of the real GDP pc ranking, with nearly 106,000 PPP-USD of 2017, followed by Luxembourg (with about 71,000), Brunei Darussalam (some 70,000), Bermuda (66,000) and Switzerland fifth (56,000). Macao SAR China comes sixth, Norway seventh, Saudi Arabia eighth, and the United States (US) ninth, with a bit more than 40,000 PPP-USD of 2017. All these countries are assigned the darkest red color in our palette. At the opposite end of this ranking, all in dark blue and bottom-up, come Mozambique, last with 460 PPP-USD of 2017, Myanmar, Ethiopia, Uganda, Rwanda (with 933), Equatorial Guinea, Malawi, Burkina Faso, Chad, Niger, Burundi and the Central African Republic (with 1200 PPP-USD of 2017). As is clear from the colors in the world map and the mentioned numbers, there was huge diversity in real GDP pc levels globally back in 1990.

Three decades later, in 2020 on Fig. 3, Luxembourg has the highest GDP pc, at nearly 112,000 PPP-USD (2017 constant value), followed by Singapore (just below 95,000) and Ireland (just above 91,000). The US comes 11th, at marginally over 60,000 PPP-USD of 2017. On the other end of the ranking, bottom-up, one finds some of the same countries as in 1990 as well as a few other: Burundi, with 711 PPP-USD of 2017 pc, the Central African Republic, the Democratic Republic of Congo, Somalia, Niger, Mozambique, Liberia, Madagascar, Chad and Malawi,

[5] The replication archive, employing MATLAB and STATA, is available via the GitHub webpage of the author: https://github.com/AlexanderMihailov.

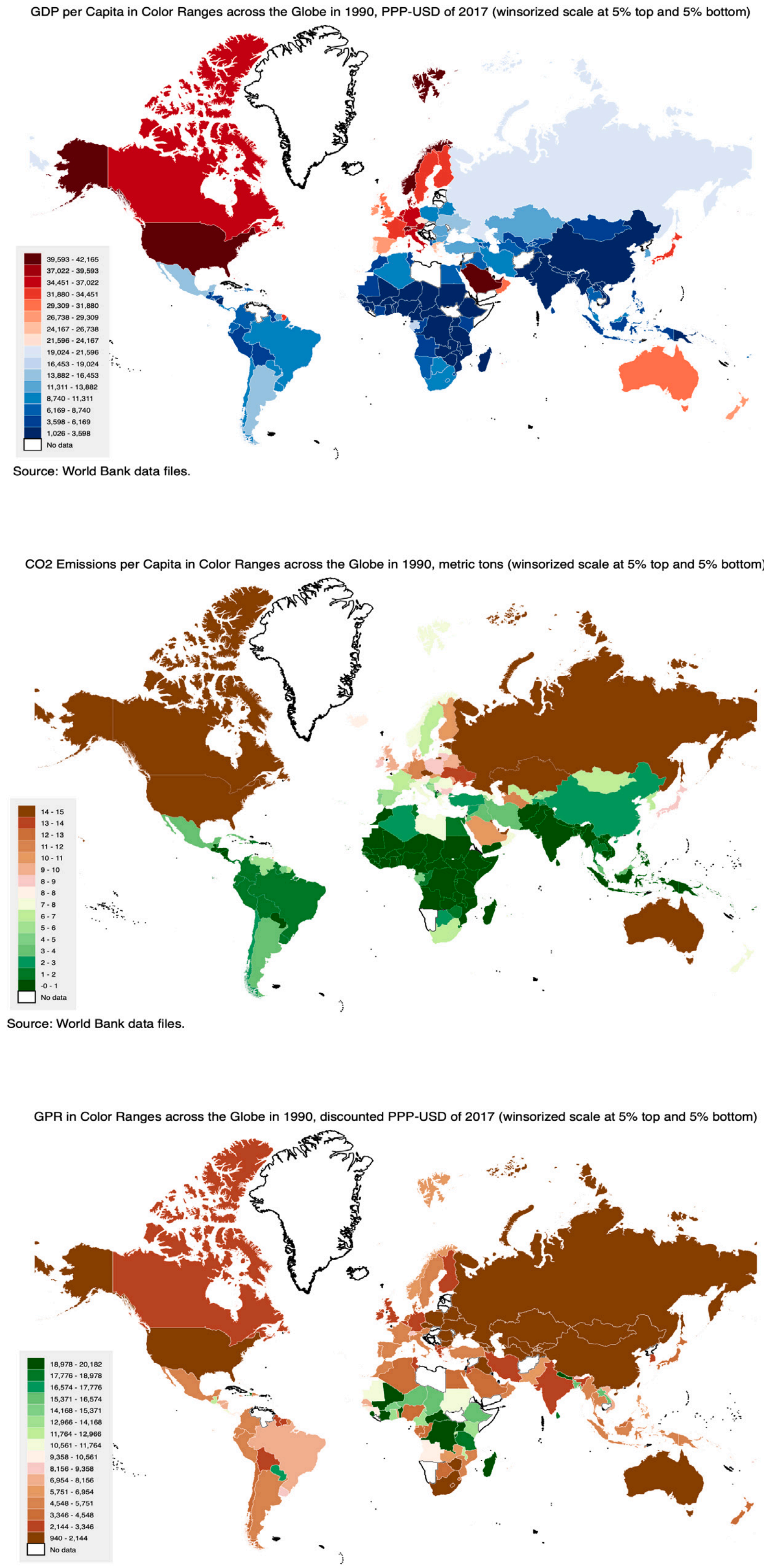


**Fig. 2.** Country color comparisons on the map of the world in 1990.
*Note*: To allow straightforward visual comparison, the color palette definitions we have chosen to work with in the present paper are intentionally kept the same for the map and stripe figures that follow. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

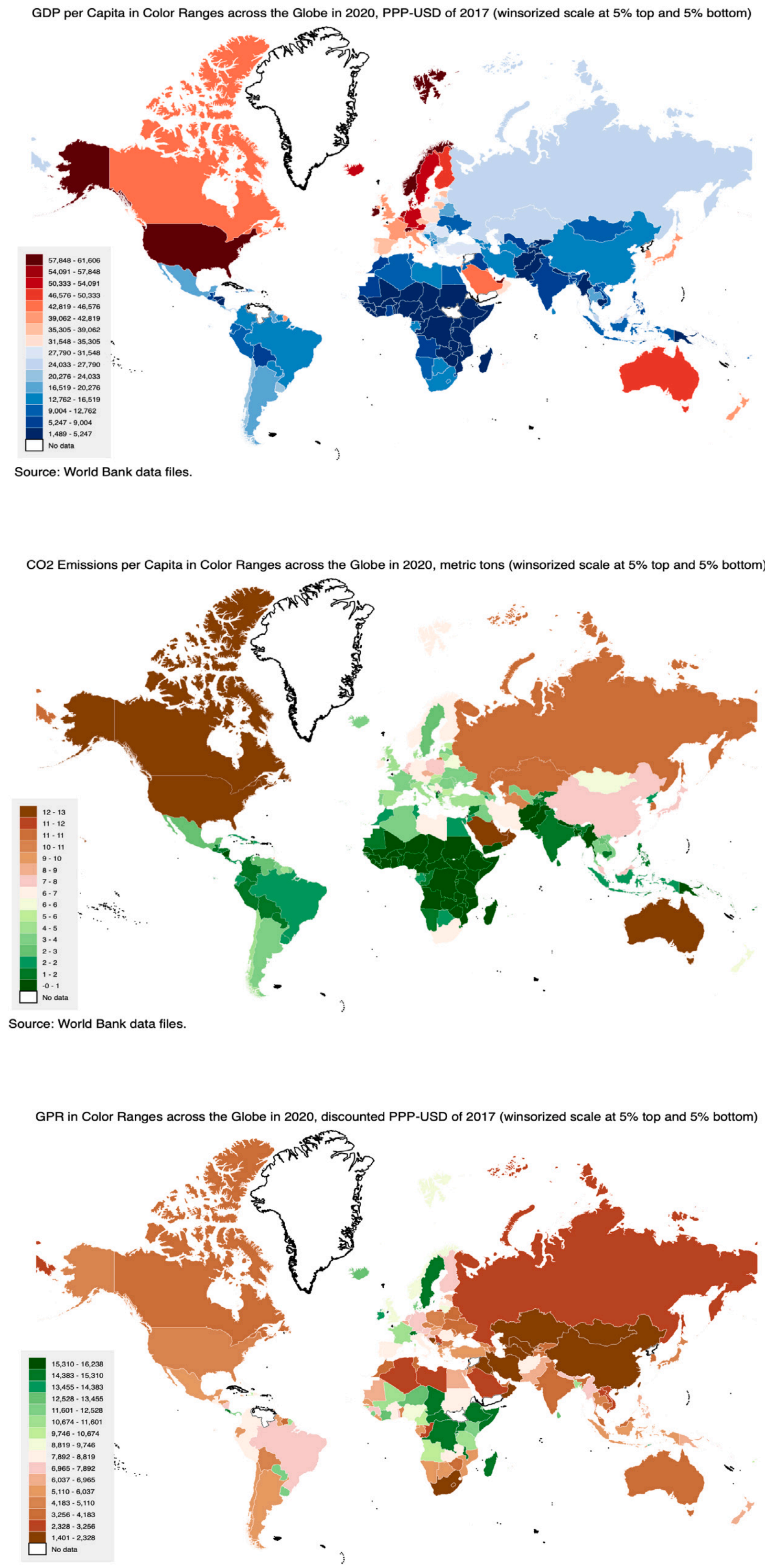


**Fig. 3.** Country color comparisons on the map of the world in 2020.
*Note*: The same as under Fig. 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

**Table 1**
Greening prosperity stripes — Descriptive statistics summary.

| | World | High-Income Cs | Upper Mid-Income Cs | Lower Mid-Income Cs | Low-Income Cs |
|---|---|---|---|---|---|
| GDP pc at PPP in intl USD of 2017 | | | | | |
| Min | 9 665.89 | 31 817.69 | 5 712.87 | 3012.71 | 1183.15 |
| Max | 16 864.89 | 50 002.95 | 16 738.56 | 6845.04 | 1966.98 |
| Range | 7 199.00 | 18 185.26 | 11 025.70 | 3832.33 | 783.83 |
| Mean | 12 684.74 | 41 141.41 | 9 964.45 | 4469.28 | 1535.74 |
| Median | 12 470.71 | 42 620.28 | 8 891.28 | 4185.14 | 1486.23 |
| CO2 emissions pc in metric tons | | | | | |
| Min | 3.84 | 8.75 | 3.02 | 1.03 | 0.25 |
| Max | 4.72 | 11.69 | 6.01 | 1.68 | 0.63 |
| Range | 0.88 | 2.94 | 2.99 | 0.66 | 0.38 |
| Mean | 4.26 | 10.91 | 4.36 | 1.28 | 0.39 |
| Median | 4.29 | 11.06 | 4.25 | 1.19 | 0.40 |
| GPRs in 'discounted' PPP-USD of 2017 | | | | | |
| Min | 2 413.90 | 2 859.95 | 1 862.32 | 2731.52 | 2133.65 |
| Max | 3 775.56 | 5 445.74 | 2 784.88 | 4232.68 | 7573.84 |
| Range | 1 361.66 | 2 585.78 | 922.56 | 1501.16 | 5440.20 |
| Mean | 2 954.68 | 3 808.76 | 2 227.60 | 3422.38 | 4261.70 |
| Median | 2 880.21 | 3 655.34 | 2 190.06 | 3514.42 | 3473.73 |

*Note:* The table reports descriptive statistics for our three key variables, as averages over 1990–2020 for the world as a whole and the four major groups of countries it is divided and classified into by the World Bank: namely, high-income countries, upper middle-income countries, lower middle-income countries and low-income countries.

with 1490 PPP-USD pc. The significant diversity in real GDP pc levels globally remains sharp in the colors of the world map in 2020 as well as in the indicated numbers. While there are around a dozen very rich economies, shown in the nuance of the darkest red (some tiny on the map and hard to spot), there are plenty that are doing relatively well, in the lighter red and lighter blue shades. Of course, one can easily see that a number of countries in the world remain in poverty (in dark blue).

Comparing the two top panels in Figs. 2 and 3, what strikes is the persistence of poverty traps in some countries and regions of the world, remaining in the dark blue spots; while in other countries and regions a process of catching-up appears visible, as respective colors change from dark blue into lighter blue (notably, China and western South America) or even light red.

Note that in several of its publications and blogs from 2023 the World Bank has discussed a threshold that could define 'prosperity'. It is set at USD 25 per person per day in 2017 PPP terms, i.e., consistent with our real GDP pc measurement here too. The 'prosperity threshold' is used in the context of a 'prosperity gap', a measure introduced to track 'shared prosperity' (see Kraay et al. (2023) for the policy paper version and Prinsloo et al. (2023) for the blog update).[6]

In terms of our data frequency, then, this prosperity threshold translates precisely into USD 9125 per year (= USD 25 per day × 365 days) and can be approximated by a split between the 3rd and 4th nuances of the blue-color palette bottom-up (from dark blue to lighter blue) in the scale of our figures. This makes easy to distinguish by the real GDP pc color assignment of our visualization methodology the countries in the world above the threshold of prosperity, i.e., all in the red nuances range plus in the top-five light-blue nuances in either 1990 or 2020, versus the countries, mostly in Africa and central Asia, that did not attain this threshold either in 1990 or 2020. This check of the real GDP pc color assignment will be important later on to accordingly distinguish what we would call 'greening prosperity (stripes)' versus 'greening development (stripes)'.

#### 4.1.2. *Emissions of CO2 per capita*

Similarly, the levels of carbon emissions pc by countries and regions in 1990 and 2020 display a considerable diversity, with some persistence as well as some changes (see the middle panels of Figs. 2 and 3).

[6] The latter can be read at https://blogs.worldbank.org/opendata/updated-estimates-prosperity-gap.

The largest CO2 emitters pc in 1990 in Fig. 2, all in dark brown (some hardly visible), are Luxembourg, with 29.5 metric tons, the UAE (29.1), Qatar (28.4), Estonia (22.0) and Bahrain (20.8); the US comes sixth (19.4), followed by Kuwait (17.4), Australia (15.4), Canada (15.1), Czechia (14.8), Russia (14.6), Kazakhstan (14.4) and Ukraine (13.3). The lowest CO2 emitters on the other end of this ranking and bottom-up, all in dark green, are Burundi (with 0.034 tons), Uganda, Nepal, Ethiopia, Mali, the Central African Republic, Benin, Burkina Faso, Chad, Niger, Tanzania, Rwanda, Sierra Leone, Madagascar and Malawi (all below 0.076 tons).

The middle panel of Fig. 3 reveals that some countries continue to be characterized in 2020 by the darkest brown spots as the largest CO2 emitters pc: these include Qatar (with emissions in 2020 of 32 metric tons), Bahrain (22), Brunei Darussalam (21.7), Kuwait (21), and the UAE (20). The US – emitting 13 tons – ranks 10th in this list, following Oman (15.6), Australia (14.8), Saudi Arabia (14.3) and Canada (13.6). Most countries in Africa and Latin America remain the lowest polluters, while many countries in Europe and China have marked an improvement.

#### 4.1.3. *Greening prosperity*

Our greening prosperity – or development – indicator for 1990, as measured in our color palette going from dark brown to dark green, is plotted for all countries on the world map in the bottom panel of Fig. 2. Burundi, with 34,351 'discounted' or 'cleaned' PPP-USD of 2017 per ton of CO2 emissions, Benin, Nepal, Mali, Haiti, Madagascar, the Central African Republic, Uganda, the Democratic Republic of Congo, Sierra Leone, Comoros, Cote d'Ivoire, Tanzania, Sri Lanka, Paraguay, Lao People's Democratic Republic, Bangladesh, Niger, Ethiopia and Chad (with 15,392 'cleaned' PPP-USD of 2017) come out on the top 20 places in 1990 in terms of GPRs, as can also be verified by the colors in the bottom map of Fig. 2. However, at this point we suggest – as was noted earlier – that a check is made for each of these countries with regard to the numerator (real GDP pc) color of their GPRs, and if this color falls within the three bottom and darkest-blue ranges of our palette scale, true for all the above countries, we would rather interpret our proposed indicator as 'greening development' (GD), not really as 'greening prosperity' (GP) in the proper sense of the word. Switzerland, one of the richest and greenest advanced economies, only ranks 39th, with 8716 'cleaned' PPP-USD of 2017 per ton of CO2 emissions, while Norway, the other advanced economy coming higher next, is 59th with 6123 'cleaned' PPP-USD of 2017 per ton. It becomes clear that our simple GPR indicator, as defined by the ratio of real GDP pc to CO2 emissions pc, tends to favor weak denominators rather than strong numerators, which is one limitation we readily admit and discuss briefly, but leave refinements for future work. On the other hand, the check of the numerator (real GDP pc) color assigned by our method mitigates the mentioned limitation, and allows to distinguish between greening 'development' country colors (when the numerator, real GDP pc, falls in the three darkest blue bottom-scale palette ranges) and greening 'prosperity' ones (otherwise).

Similarly, the bottom map of Fig. 3 shows the global cross section of the GPR indicator for 2020. The continued absence, as was in 1990, of carbon emissions data for some of the richest small or island economies – often those dominated by financial service sectors that are not emitting much CO2 pc, such as Bermuda, the Cayman Islands, Hong Kong, Macao SAR China, San Marino – means that they are not included in a fairer, more exhaustive calculation of the greening prosperity ratios. This data unavailability, which in the near future is likely to be remedied, accentuates further the obvious weakness of our initial and simply defined greening prosperity indicator we just mentioned, namely to 'inflate' at higher values (due to tiny denominators) – and as seen in the green nuances around central Africa on the map – some of the poorest countries in terms of GDP pc that emit very little carbon dioxide pc. The darkest green color symbolizing the highest GPRs or GDRs is, thus, attained by about a dozen of countries, some quite poor and some quite rich: the Democratic Republic of Congo comes first in such a ranking for 2020 (corresponding to its GDR of just above 32,000 'discounted' PPP-USD of 2017 per metric ton of CO2 emissions), followed by Somalia (some 28,000 'cleaned' PPP-USD of 2017 per CO2-emitted ton), Rwanda (nearly 19,700) and the Central African Republic (just above 19,000). As was in 1990, but with a definite progress in 2020, much richer Western economies that do not have particularly high levels of carbon emissions in per capita terms now come only a little further down in this ranking. For example, Switzerland has moved up seventh (with GPR of about 16,800 discounted PPP-USD of 2017 per ton), and Sweden eighth (15,800) – both attaining the darkest green color too (due to the winsorizing effect). Ireland (13,500), Malta (13,120) and Iceland (13,080) rank 14th, 16th and 17th, respectively. In the majority of other countries, the level of greening prosperity, or indeed greening development, remains too low – below 10,000 'cleaned' PPP-USD (2017 value) per ton of CO2 emissions – shown by the dominant medium-to-dark brown color shades. This is either because the majority of the world's economies are considerable carbon emitters per capita (i.e., ratios dominated by the denominator) or because many economies have relatively low real GDP pc (i.e., ratios dominated by the numerator), or both.

Moreover, while not adding new information on top of standard time-series or cross-section plots, our greening prosperity – or development – colormaps as well as their 'stripes' version, which we present and analyze in detail hereafter, are useful because colors have the power to impress and get through to even a nonspecialized public worldwide, as suggested in the color design and psychology literature, e.g., Gao and Xin (2006), Elliot (2015), Wilms and Oberfeld (2018) and Jonauskaite et al. (2020) and the special issue editorial by Jonauskaite and Thorstenson (2024), thus raising awareness and potentially mobilizing action. Our hope is that the proposed innovative visualization will highlight clearly how significant the levels of carbon emissions have become and how far even the advanced economies in the world still remain from a desirable goal of a genuine green(ing) prosperity, no matter the trend of 'decoupling' of economic growth from CO2 emissions observed since the 1990s in most of them, and partly due to offshoring polluting industries. Realizing this dangerous state of affairs will remind us that we should act decisively as early as now in order to mitigate and reverse the negative – and recently extreme – influences of climate change on life on our planet.

### *4.2. Sample selection for comparative colormap stripes by country across time*

We, now, present the most original and colorful (literally) visualization of our greening prosperity stripes indicator and its two determinants (in the numerator and denominator). Our comparative colormap visualizations that will be discussed next depict, as a first step, graphs of real GDP pc at PPP in international USD of 2017, CO2 emissions pc and the resulting greening prosperity ratios, now as stripes, for four major economies during the period 1990–2020. Then, we also highlight our analogous colormap stripes for Switzerland, notably the richest and greenest economy, and for the world as a whole. Our larger sample in the online appendix (and in the discussion paper version) adds 18 more countries or World Bank country groups (illustrated in symmetric figures each with 9 subplots of stripes across time in 2 subsamples), for a total of 24 economies. Our total sample of comparably-defined stripes in colors by country from 1990 through 2020, thus, includes one low-income country (Mozambique), one lower middle-income country (India), five upper middle-income countries (Brazil, Bulgaria, China, Mexico and Russia), 11 high-income countries (Australia, Canada, France, Germany, Italy, Japan, Poland, Saudi Arabia, Switzerland, the UK and the US), and six country groups (the world, high-income countries, upper middle-income countries, lower middle-income countries, low-income countries and the EU). In selecting the countries and the country groups for key illustrations in the main text and for a more comprehensive comparison in the online appendix, we have been guided by the importance of their respective economies, and/or the extent to which they emit CO2, and/or to represent the diversity of their societies and institutions, originating in different geographical continents and in various stages of economic development.

#### *4.2.1. Real GDP per capita*

Beginning with the numerator in the greening prosperity ratio, Fig. 4 plots the four major economies considered here in the main text in terms of the same 16 blue-to-red color nuance palette as in the top panels of Figs. 2 and 3 – that is now popular due to the work of Hawkins (2018) on the climate warming stripes. By analogy with the typical terminology in (macro)economics of 'heating up' versus 'cooling down' of the economy, we have opted to assign red versus blue color nuances to higher versus lower real GDP pc values.

This is a colormap visualization that is valuable because the pattern of nuances is (i) unique for each country and depicts its own data as stripes across time on the same horizontal scale but is as well (ii) directly comparable across countries, since the scales on the vertical axis are, by construction, the same too. In this sense, and by definition, the country color stripes across time are standardized and represent a unique pattern by country – similar to the barcode symbology of the Universal Product Code (UPC).

What do we learn from these country color stripe images across time, in addition to the corresponding conventional time-series or cross-section visualization?[7] First of all – and similarly to troughs after peaks in time-series plots – stripes that tend to move from the blue or lighter red nuances into the darker red but reverse for some years capture recessions and crises in real GDP pc: one can notice the GFC of 2007–2009 and – less so – the start of the pandemic in 2020 in the EU and the US colormap subplots (and in many of the graphs for the advanced economies – and also Russia in case of the GFC – in figures 10 and 11 in the online appendix.)

Second, relatively narrow (compared to broad) country stripes across time with color going from darker into lighter blue or from lighter into darker red nuances capture relatively strong (compared to

[7] Presented – to save space here – in the appendix to the discussion paper version, Mihailov (2023).

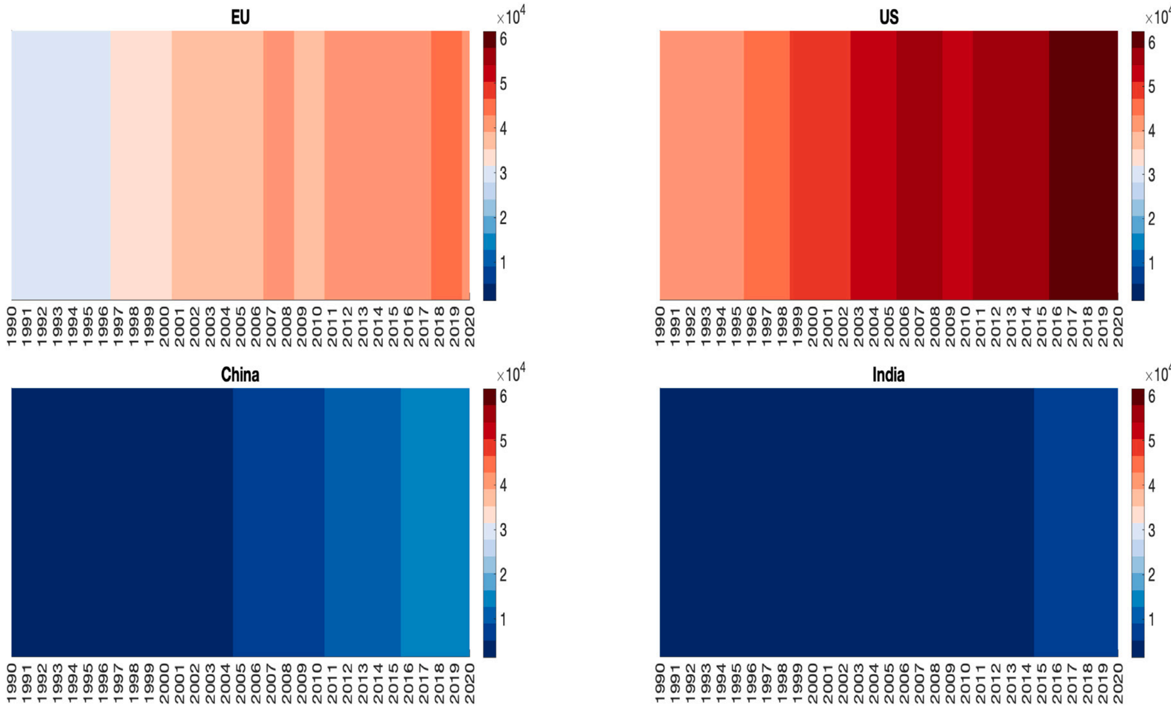


**Fig. 4.** Real GDP pc at PPP in international USD of 2017 – Colormap stripes comparison for major economies across time.
*Note*: The illustration and focus in the main text is on these four major countries/regions, while many more similar figures are provided in the online appendix, for broader comparisons: the vertical and horizontal scales are kept identical on all graphs on purpose, for a visible comparability. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
*Source:* World Bank, https://data.worldbank.org/indicator/NY.GDP.PCAP.KD.

weak) trend growth in the level of real GDP pc. These narrower stripe patterns appear clearer for the US and – less so – the EU (and the UK, France, Poland, Russia and Saudi Arabia in the appendix). By contrast, India has only two broad blue stripes, capturing slower trend growth in real GDP pc. China, on the other hand, marks some acceleration in the real GDP pc stripe pattern change after 2004. In the case of both these populous countries, demography has played a decisive role in influencing real GDP per capita measures, but in opposite directions: as a weight on per-capita economic growth for India and as an accelerator for China during its one-child policy period. Like in China, slower population growth in the EU and the US has similarly ‘inflated’ the illustrated per-capita real GDP measures.

#### *4.2.2. Emissions of CO2 per capita*

Now moving to the denominator in our greening prosperity ratio, CO2 pc emissions, we change the definition of the color palette to better suit our purpose. Consistent with the middle panels of Figs. 2 and 3, we apply a new color and nuance scale that moves from (dark) green to (dark) brown as a country emits a higher volume of CO2 pc in metric tons.

What is insightful in the collection of color stripes in Fig. 5 (and in the corresponding figures 12 and 13 in the appendix) is that we can observe countries that become greener when going along time from 1990 to 2020, as they have reduced gradually their CO2 emissions pc: this visual impression applies to the EU (in Fig. 5) and Switzerland (in Fig. 7) in the main text (and the UK, France and Italy as well as – with more hesitation captured by temporary stripe pattern reversals – Bulgaria, Poland, Germany, Japan and Russia in the appendix). We, however, also observe the opposite trend in the stripe pattern, as some economies are not becoming greener over time, but lighter green or browner instead, i.e., increasing their emissions of CO2 pc: these are China and India in the main text (as well as the upper middle-income countries and Saudi Arabia in the appendix). A third group, that is, the US in the main text (as well as Australia and Canada in the appendix), cannot come out – over three decades – of the dark brown nuance of persistent relatively high CO2 emissions (while during the same period a fourth group, namely, the low-income countries with Mozambique as their representative in the appendix, retain the dark green of persistent relatively minimal CO2 pc emissions). But note that it is the winsorizing effect that produces the flat dark brown color here for the US, hiding progress this country has made from 19.4 to 13 metric tons of CO2 emissions, according to the numbers we provided when analyzing Figs. 2 and 3 earlier.

Like in the case of the numerator of our GPR discussed already, here its denominator also can be decomposed into influences of demography on the per-capita level of CO2 emissions: countries with relatively faster growing population, in particular India in our period of analysis, will have the latter indicator relatively mitigated, due to the increasing denominator. By contrast, countries switching relatively faster to renewable sources in energy generation, such as the EU or Switzerland in the main text (or also France in the appendix) will have their indicator of CO2 emissions per capita mitigated too, but now due to the declining numerator.

In the present context of visualizing per-capita CO2 emissions stripes by country over time, our approach appears even more effective and, therefore, worthwhile, as it assigns well-understood colors to the ecological dimension of economic growth we highlight here, i.e., the denominator of our GPRs. Even a nonspecialist can recognize the trend in the colors from ‘polluted’ brown to ‘cleaned’ green or vice versa across countries or regions over time, which hopefully makes the issue of environmental sensitivity and climate change mitigation salient in social perceptions worldwide, thus raising awareness and, ultimately, coordinated action across the globe.

#### *4.2.3. Greening prosperity*

In this most important aspect of our study, when we are now presenting the greening prosperity stripes visualization in Fig. 6, the logic of color meanings and conventions implies another redefinition.

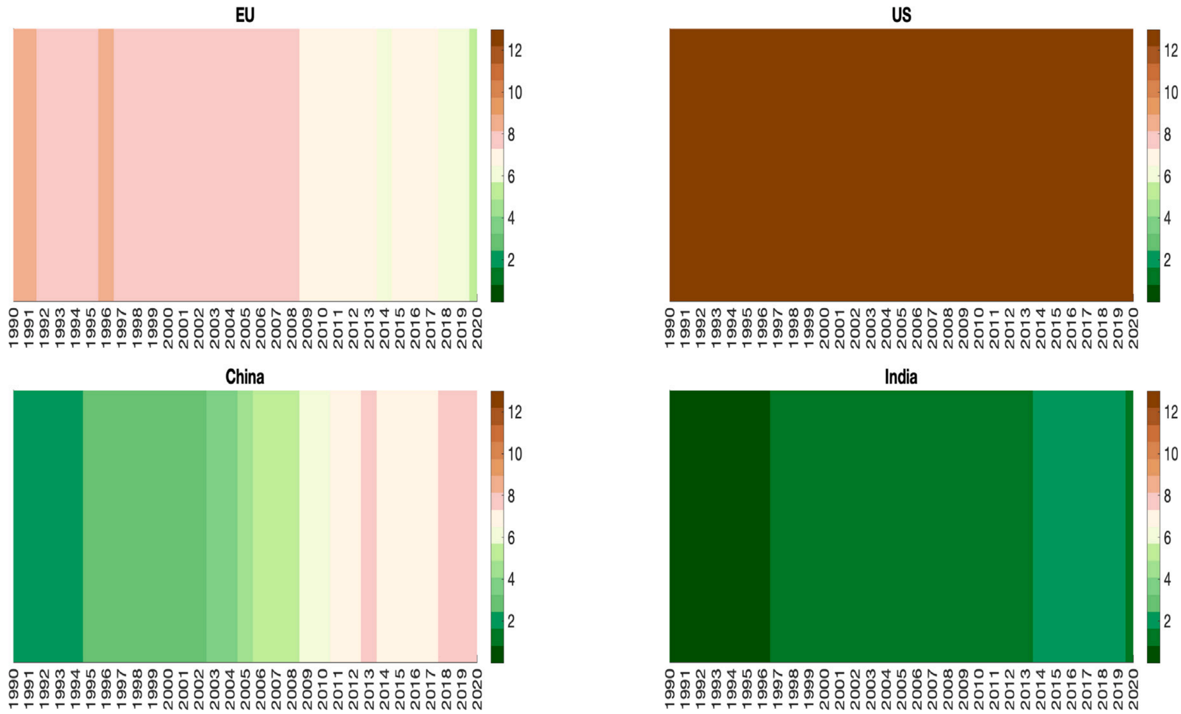


**Fig. 5.** CO2 pc in metric tons – Colormap stripes comparison for major economies across time.
*Note*: Same as for the previous figure. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
*Source:* World Bank, https://data.worldbank.org/indicator/SP.DYN.LE00.IN?name_desc=true.

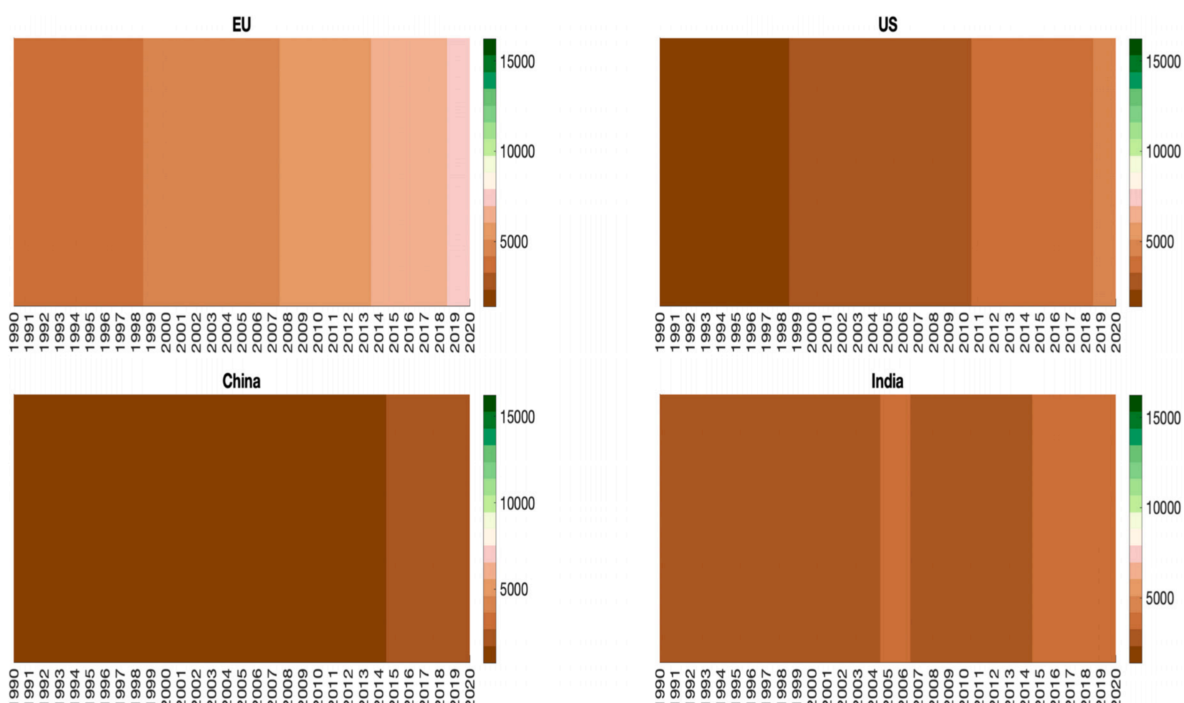


**Fig. 6.** Greening prosperity at PPP in international USD of 2017 'discounted' by CO2 emissions pc in metric tons – Colormap stripes comparison for major economies across time.
*Note*: Same as for the previous figure. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
*Source:* World Bank, https://data.worldbank.org/indicator/NY.GDP.PCAP.KD and https://data.worldbank.org/indicator/SP.DYN.LE00.IN?name_desc=true.

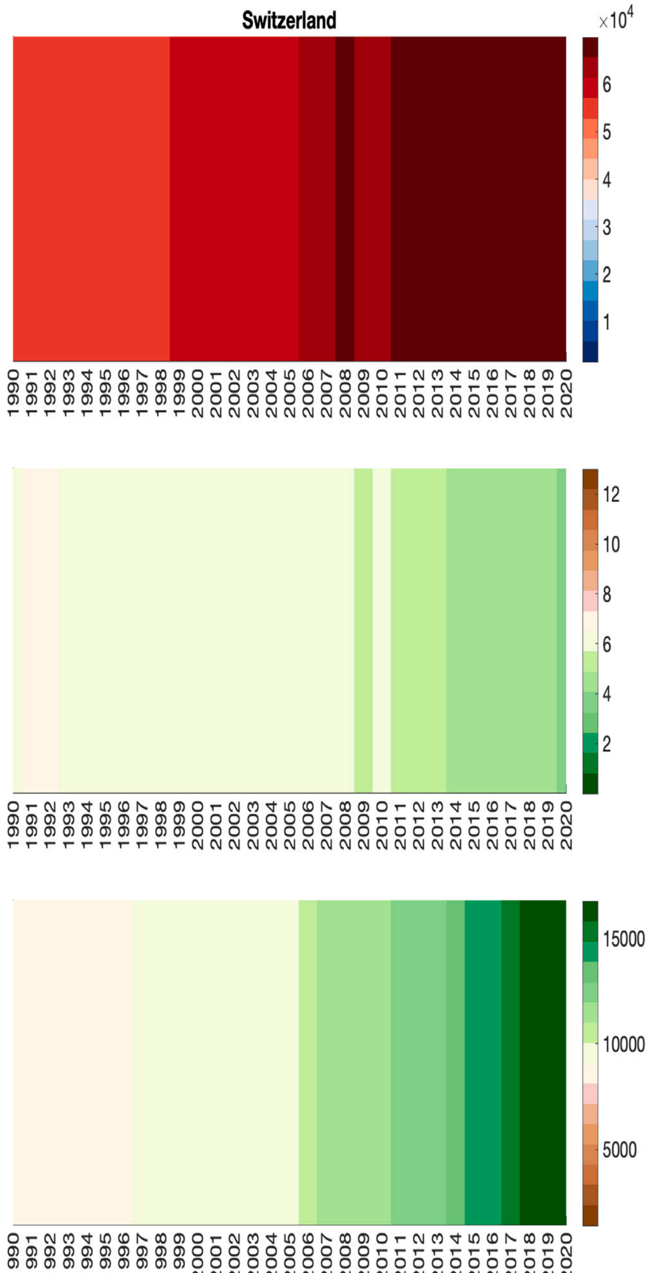


**Fig. 7.** Switzerland has definitely become richer as well as greener.
*Note*: The figure presents 3 respective subplots of unique per country but directly comparable within our sample colormap stripes across time obtained by winsorizing the 2020 cross-section of all countries in the world at 5% and 95%. It presents the greening prosperity ratio for Switzerland (bottom panel) as well as its numerator (top panel) and denominator (middle panel). The vertical and horizontal scales are kept identical as in all similar graphs in the main text and online appendix on purpose, to ensure visual comparability. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
*Source:* World Bank, https://data.worldbank.org/indicator/NY.GDP.PCAP.KD and https://data.worldbank.org/indicator/SP.DYN.LE00.IN?name_desc=true.

Indeed, we use again the same color and nuance palette in 16 ranges as in the preceding figure, mapping CO2 emissions pc, but we now reverse the direction, showing brown in the bottom of the (winsorized) scale and green in the top – again, consistent with the bottom panels of Figs. 2 and 3.

Accordingly with this redefinition, we observe many economies going lighter brown or even sometimes really greener, notably Switzerland (bottom panel in Fig. 7) and the EU (top-left panel in Fig. 6) and – less so – the US and China (respective panels in Fig. 6) in the main text (and most countries in figures 14 and 15 in the appendix – in particular, France and the UK) – as we move from 1990 to 2020. There are, however, exceptions where the brown color stripes dominate in the right-hand side of the panel subplots, rather than in the left-hand side, thus exhibiting a worsening of the greening prosperity indicator (such is the case of Saudi Arabia in the appendix). For many countries or groups, though, the speed of moving from dark to lighter brown and hopefully into green is slow, as visible in the dominating dark brown stripes turning into lighter brown once or twice during the 31 years of data, or with temporary reversals: such are the cases of India and the world as a whole (bottom panel in Fig. 8) in the main text (as well as the upper middle-income country group, Brazil, Mozambique, Canada, Mexico, Russia and – to a minor extent – Poland and Bulgaria in the appendix).

#### *4.2.4. Switzerland's greening prosperity stripes and their determinants*

It is also insightful to present our comparable colormap stripe visualizations across time for a single country, and analyze to what extent our approach allows to infer whether the greening prosperity ratio has been influenced more by its determinant in the numerator or in the denominator. To illustrate this other possible informative use of our stripes, Fig. 7 highlights the wealthiest and cleanest country among the 24 economies in our larger sample (including the additional figures in the online appendix) according to our greening prosperity indicator, Switzerland. This may not come as a surprise.

Switzerland is one of the richest advanced economies in terms of real GDP pc (seen in the color stripe sequence in the top panel against the right-hand-side scale allowing comparison to all other countries) as well as one of the greenest among them in terms of CO2 emissions pc (seen in the color stripe sequence in the middle panel against the right-hand-side scale allowing comparison to all other countries). Indeed, Switzerland is not heavily reliant on high-polluting industries. Instead, its economy is propelled mostly by low-emission sectors, efficient energy use and stringent environmental policies. As a result Switzerland's greening prosperity stripes (in the bottom panel) reach the top range of the (winsorized) palette scale in the right-hand side during the years of 2018, 2019 and 2020. One can also infer from the colors measured against the respective right-hand side scale in the top/numerator and the middle/denominator panels that the GPR for Switzerland has been more strongly influenced by the numerator, which does attain in color the (winsorized) maximum of the palette in the right-hand side, whereas the denominator does not reach in color the (winsorized) minimum of the palette. That is, real GDP pc has been the main driver (among the two captured in the numerator and the denominator of our GPR) behind the greening of the prosperity stripes for Switzerland.

#### *4.2.5. The world's greening prosperity stripes and their determinants*

Now, moving to the world as a whole, we analyze Fig. 8, which has the same structure as Fig. 7. Yet, what becomes clear immediately from the color stripes and their width is that the world as a whole has been very slowly and only minimally increasing its real GDP pc as well as its CO2 emissions pc, with an overall effect of somewhat 'greening' – but still remaining down in the browner nuances of the color palette – its prosperity stripes. Indeed, the world, on average, has passed the threshold of prosperity some time around 2005–2006, as seen in the top panel when the lighter blue color of the 4th bottom-up palette range has been crossed, which is encouraging. Yet, in all three cases of the numerator, the denominator and the ratio, the respective right-hand scales show that the world as a whole continues to occupy a few ranges near the bottom of these palette scales, which for the middle panel of CO2 emissions pc is also a positive outcome. Nevertheless, the progress

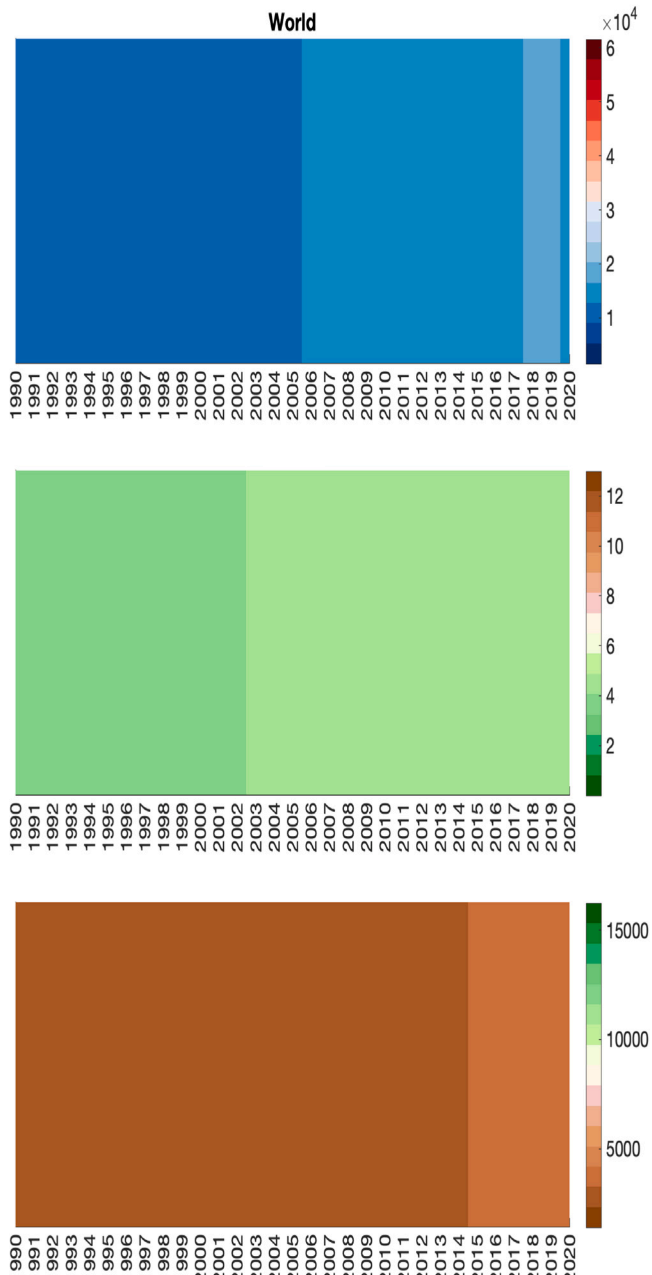


**Fig. 8.** The world has marginally become richer and greener.
*Note*: The figure presents 3 respective subplots of unique per country or region but directly comparable within our sample colormap stripes across time obtained by winsorizing the 2020 cross-section of all countries in the world at 5% and 95%. It presents the greening prosperity ratio for the world as a whole (bottom panel) as well as its numerator (top panel) and denominator (middle panel). The vertical and horizontal scales are kept identical as in all similar graphs in the main text and the online appendix on purpose, to ensure visual comparability. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
*Source:* World Bank, https://data.worldbank.org/indicator/NY.GDP.PCAP.KD and https://data.worldbank.org/indicator/SP.DYN.LE00.IN?name_desc=true.

the world on average has made on all three panels between 1990 and 2020, as evident in the color stripes evolution, hides a huge diversity across countries and country groups (as we saw and discussed already).

To conclude this section, we would restate here that our novel colormap stripe visualization allows easy comparisons of a country's performance over time against that of other countries. Hence, it appears insightful and adds value to the presentation of the analysis at hand, by essentially getting it across to a wider and unspecialized audience in an obvious, straightforward way. Moreover, we should not compare the GPRs or GDRs in isolation, without considering their two components, the numerator of real GDP pc, which is important to distinguish (in colors, in our case) greening prosperity from greening development in interpreting these ratios, and the denominator of CO2 emissions pc, each of which can be driven in turn by its own numerator or denominator (the population, in both cases). Not separating our ratio indicator from its determinants (numerator and denominator) is essential in being able to provide a more informative analysis using our colormap methodology, as we attempted to explain and illustrate.

## 5. Policy implications

Our present work was intended mainly to propose a straightforward and comprehensive visualization of the comparative degree of convergence versus diversity in terms of real GDP pc, CO2 emissions pc and the resulting ratio of greening prosperity across the globe. Its purpose was to raise wide-spread awareness of the urgency of climate change mitigation, an issue of the highest order of magnitude that our world has to solve today. Hence, the policy implications of our paper are immediate and immense.

A key policy implication is that academic research needs to disseminate its most important results to a mass audience, and in such a nonspecialist dissemination what matters is that pictures or images, especially in colors, 'speak louder than words'. The import of the current work also lies in the effectiveness of such colormap stripe visualization, popular recently in scientific articles as well as on social media. Without doubt, the use of color nuances along the naturally perceived brown-to-green scale, given the task of environmental greening at hand, constitutes the main visualization contribution of our paper. As the literature in psychology and color design that we cited earlier suggests, colors evoke emotional responses in human beings, and for this reason may well help mobilize environmental action.[8]

In addition to raising awareness and alarm, possibly coordinating action too, our greening prosperity indicator could be directly used to track progress for each country along the goal of net zero emissions in the years and decades to come, as we suggested. Actually, there has been much interest, discussion, data collection and dynamic analysis with regard to the possible paths toward greening the global economy. Notably, the OECD (2025) Net Zero+ Project[9] puts together and synthesizes the climate-related work of over 20 OECD thematic committees. The aim is "to provide analysis and recommendations for driving a rapid transition to net-zero emissions while building resilience to the inevitable physical impacts of climate change". The Net Zero+ Policy Paper Series and the Green Growth and Sustainable Development (GGSD) Forum are the two channels along which the above tasks are being implemented. Among the key themes and recommendations coming out of the project, it is not surprising to find the conclusion that the net-zero transition needs to be "not only swift but also resilient and durable, including by future-proofing strategies against potential disruptions and evaluating the economic implications of accelerated action". In particular, people should be placed "at the center of the

[8] A related aspect of the policy implications of this 'positive' (awareness and visualization) paper is our conviction that the world should immediately act to save the planet, from a normative point of view too. In Ferret Mas and Mihailov (2021), https://www.reading.ac.uk/web/FILES/economics/emdp202116.pdf, we have already addressed the issue of climate change mitigation from the perspective of moral philosophy and the politics and economics of intergenerational climate justice.

[9] https://www.oecd.org/en/about/programmes/net-zero-building-climate-and-economic-resilience.html.

net-zero transition, recognizing and addressing its wide-ranging social implications".

Along such research that focuses on human quality of life and the social implications of the green transition, Huo et al. (2023) quantify the CO2 emissions required for achieving decent living standards (DLS), as defined in Rao and Min (2018), especially in emerging market economies with much lower standards of living. Their results show that, compared to other regions, achieving DLS in emerging Asian and African economies will result in more additional CO2 emissions, particularly in the DLS indicators of Mobility and Electricity. Achievement of DLS in emerging economies will result in 8.6 Gt of additional CO2 emissions, which should not jeopardize global climate targets. However, a concerning trend arises as more than half of the emerging economies (62 out of 121) will face substantial challenges in aligning their expected emission growth for achieving DLS with their national emission mitigation targets. Notably, the DLS approach of Rao and Min (2018) could also be considered in future research as an option to extend our 'first pass' here on distinguishing 'greening prosperity' versus 'greening development', which we based on the World Bank prosperity threshold, as discussed.

To link once again the work we proposed in this study with the immediate policy implications it attempts to address, we would restate the huge concern in science and media that 2023 and then 2024 have become the warmest years on record, as an average for the world. Moreover, what is really worrisome is that August 2023 was estimated to have already been around 1.5 degrees Celsius hotter than the pre-industrial average for the 1850–1900 period; whereas – as widely known – pursuing efforts to limit the global temperature increase to 1.5 degrees Celsius compared to these pre-industrial levels is the goal of an unprecedented effort in international cooperation, namely, the Paris Agreement on climate change signed by 196 countries in 2015 (and ratified by 2020). In such context, can public perceptions and views influence the formulation and implementation of appropriate actions by policymakers?

Indeed, some literature has looked at the importance of public opinion to implement green policies. For instance, Chai et al. (2024) argue that confronted with haze pollution, people have begun expressing more and more their opinions online to demand restrictions on pollution discharge by enterprises to protect their health rights. Employing text content analysis to examine the role of public opinion as an intermediary in the relationship between haze pollution and the formulation of environmental regulation policies and using a dataset of 460 environmental regulation policy documents and over 800,000 public opinions on environmental issues spanning from January 2011 to December 2021, these authors find that public opinion exerted a significant intermediary effect by linking haze pollution and environmental regulation policy tools.

To further situate the immediate policy implications of our work along the perspective of the increasing accumulation and dissemination of comparable climate-related socio-economic data worldwide, we would note that the OECD Green Growth database[10] compiles selected indicators to monitor progress toward green growth in order to support policymaking and inform the public at large. The database covers OECD member and accession countries and key partners, including big economies and important polluters such as Brazil, China, India, Indonesia and South Africa.

As was noted, our measure of greening prosperity is related, in fact reciprocal, to the traditional measure of energy efficiency, e.g., Kang and Kang (2022) and Fisera et al. (2024), also interpreted as the emissions intensity of one unit of GDP, in the environmental literature. However, in our colormap implementation the latter – and reciprocal – interpretations extend to greening prosperity world maps (in a cross-section) or comparable across countries greening prosperity stripes (over time). This makes our contribution authentic and comprehensible for everybody, as people (and even children) can easily recognize color patterns going from brown to green nuances, or vice versa. In particular, Fisera et al. (2024) use the reciprocal of our greening prosperity ratio, and interpret it as CO2 emissions per dollar in addressing the open empirical question of whether and how financial deepening, which contributes to economic development, affects the carbon intensity of production. In a global sample of 125 economies from 1990 to 2019 and using a local projections approach, they find that, on average, financial deepening leads to a relative increase in CO2 per dollar of GDP, indicating that financial institutions finance relatively more carbon-intensive investments and consumption. However, the good news is that an improved institutional environment mitigates this adverse effect of financial deepening: that is, conditional local projections reveal that in countries with more environmental regulations, a stronger rule of law, and a financial system that is relatively more market- than bank-based, financial deepening does not lead to higher CO2 emissions per dollar of GDP.

Further along the lines of proposing novel indicators, as we did in the present study, Lau et al. (2023) construct a new index of green quality of the energy mix in the context of the environmental degradation model and estimate its impact on the environment in a panel data setup comprising 36 OECD countries from 1970 to 2021. The key finding they highlight is the beneficial impact of the green quality of energy mix on the quality of the natural environment. They claim that such a finding supports using renewable and green energy to sustain economic development while minimizing environmental costs. Yet, on the other hand, economic development is found to be detrimental to environmental quality management, and developed countries cannot yet decouple economic growth and environmental pollution. While somewhat encouraging, the findings in this study are valid only for the OECD countries.

Within a similar context of investigation, and again limited to only the OECD countries, Marra et al. (2024) examine (i) whether technological and structural shifts result in reduced energy intensity and lower CO2 emissions and (ii) whether such technological and industrial transformations interact and have a joint impact on the environment. The authors employ a PVAR model in first differences for a panel of 34 OECD countries spanning from 1994 to 2019, as well as for a cluster of countries exhibiting the most compelling trend in energy intensity. They find that technological change impacts CO2 emissions exclusively within the identified cluster, whereas structural change does not directly affect the reduction of these emissions. Nevertheless, structural change acts as a catalyst for green innovation and reduced energy intensity. Moreover, improvements in energy intensity lead to lower emissions and spur both technological and structural transformations.

The policy implications and social dimensions of the green transition outlined in the present section stress once again the importance of simple but impressive visualizations such as our world maps and comparative country stripes in color to make scientific facts about CO2 emissions and their interactions with economic prosperity salient and understandable by the common people. In turn, societies can further put pressure on policymakers to formulate and implement appropriate policies within relevant time-frames. This chain of logic confirms the necessity of communicating science clearly and sharply in order to raise public awareness and policy action in crucial domains of knowledge and life, as we attempted to do in an innovative and hopefully efficient way.

## 6. Concluding remarks

In this initial work, and paper, a basic concept, its measurement and visualization was proposed, but more remains to be done. In essence, we have attempted to show the visualization power of the colormap

[10] https://stats.oecd.org/wbos/fileview2.aspx?IDFile=0eddc076-a4f9-4a2b-8e86-4190c8523b59.

approach, depicting intuitively and comparing in a straightforward way that is easy to convey and understand even by nonspecialists similarities and differences in all countries around the world in terms of real GDP pc, CO2 emissions pc and the resulting ratio of the greening prosperity maps and stripes.

Nevertheless its obvious advantages, such as simplicity of design, intuitive power and effectiveness of visual impact, we discussed as well some limitations of our greening prosperity indicator. Indeed, it was meant as a first pass or approximation. Hence, several avenues for further exploration, refinements and improvement remain. We would enumerate at least the following desirable extensions: (i) prosperity may be measured along several dimensions, two of which were illustrated here (real GDP pc, exhaustively, and life expectancy at birth, minimally, as an alternative or complement) – and a composite index could be constructed out of such multiple ingredients; (ii) the same applies to environmental pollution that capture the degree of 'greening' or 'browning' of the global and national economies beyond, simply, CO2 emissions but including other GHG emissions; (iii) the analysis could be extended to tracking greening prosperity requirements and scenarios for the future, in particular country paths to net zero symbolized in comparable colors; (iv) as was noted in the beginning, the GPRs we constructed ignore 'imported emissions', that is, emissions indirectly generated by a country by importing high-emission products, such as steel, aluminium, cement, electricity, plastics and fertilizers, a major issue which is expected to be addressed, for instance, by the EU Carbon Border Adjustment Mechanism (CBAM), and these omissions could be integrated; (v) the proposed comparable colormap stripes across countries sometimes do not capture adequately progress made within the bottom or top stripes of the worldwide scale, due to the winsorization enabling the appearance of a larger number of stripes (as was discussed in the case of the US single greening prosperity flat brown stripe); (vi) finally, and as was also briefly suggested, the World Bank prosperity threshold we used could be complemented by incorporating some index of 'decent living standards'.

## Declaration of competing interest

The author declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The World Bank data used as well as the MATLAB and STATA code to generate the results and figures are available via the GitHub webpage of the author: https://github.com/AlexanderMihailov.

## Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.ecolecon.2025.108818.

## Data availability

Data will be made available on request.

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