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DEGROWTH IS ESSENTIAL TO ACHIEVE AND SUSTAIN GLOBAL NET ZERO EMISSIONS

Martin John Bush

Chemical Engineer and Climate Reality Project, Montreal, Canada.

martin.bush@outlook.com

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ABSTRACT:

This research examines the relationship between carbon emissions and economic growth. The Paris Agreement target of net zero carbon emissions by 2050 is found to be achievable and sustainable but only under very specific conditions. Employing a modified form of the Kaya identity, an analysis of the relationship between carbon emissions and economic growth across a majority of countries shows that carbon emissions cannot be fully decoupled from growth. Emission intensities demonstrate a lower bound of approximately 50g of carbon dioxide equivalent per dollar of Gross Domestic Product (GDP). Further analysis shows that it is not possible to maintain a condition of net zero emissions after 2050 if economic growth continues to rise—even when emission intensities are reduced to a minimum. Carbon inequality in Europe and USA is disaggregated by income cohort to demonstrate that under conditions of sustainable net zero emissions, the bottom 50 percent of the distribution can increase their share of GDP, but the middle 40 percent and especially the top 10 percent of the distribution must substantially reduce their per capita emissions. Economic growth is not constrained in low- and middle-income countries but their emission intensities must be kept to a minimum. This analysis leads to the conclusion that some form of post-growth scenario must be envisaged for high-income countries if the Paris Agreement target of net zero emissions is to be not only achieved but maintained over the second half of the century.

KEY-WORDS: Net-zero emissions, Post growth, Kaya identity, Energy intensity, Negative emission technologies, Carbon inequality.

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1. OBJECTIVES AND MOTIVATION

The objective of the analysis that follows is to examine in greater detail the claim that greenhouse gas emissions can be completely decoupled from economic growth. This assertion conveys the implication that this degree of decoupling would allow economic growth to continue to rise with no associated increase in the level of greenhouse gas (GHG) emissions.

Many countries have already started to reduce their emissions of greenhouse gases. One projection estimates that nearly 60 countries will have peaked their emissions by 2030, accounting for 60 % of global emissions. Among the countries that have peaked already or have a commitment that implies a peak by 2030 are some of the world biggest emitters, including China, the United States, Russia, Japan, Brazil, Germany and Mexico [1].

The question that arises as emissions continue to decline in countries that are growing economically is: how low can they go? Emissions cannot decline to zero, but they could potentially decline to a condition of *net zero*: where the natural carbon sinks compensate for the residual emissions that remain after the decline bottoms out. However, where does this point lie and can a net zero condition be maintained should economic growth continue, given that the natural carbon sinks are unlikely to increase their capacity to absorb carbon dioxide from the atmosphere? If anything, forest lands may be losing absorptive capacity due to wildfires and infestation by insects, while the capacity of the oceans to absorb carbon dioxide may also be limited. This logic suggests that the ratio of carbon emissions to GDP may continue to decline, but that there is a limit—which would be indicated by a minimum value for this metric. If economic growth continues past this point, carbon emissions will inevitably start to rise once again.

If such a limit can be detected and measured, it can be argued that economic growth should not increase past this point. In other words, since it is incontrovertible that carbon emissions lead to increased global temperatures, for rising global temperatures to eventually decline, economic growth should not be allowed to exceed the level where the ratio of carbon emissions to GDP has declined to its minimum value.

2. INTRODUCTION

Can economic growth be completely decoupled from emissions of greenhouse gases? In his ground-breaking book, *Prosperity without Growth*, economist Tim Jackson stressed the importance of differentiating between relative and absolute decoupling:

- **Relative decoupling** refers to a decline in the ecological intensity per unit of economic output. In this situation, both Gross Domestic Product (GDP) and emissions continue to rise, but emissions rise more slowly.
- **Absolute decoupling** refers to a situation in which emissions decline in absolute terms even as GDP continues to rise [2].

The concept of peaking clearly implies a subsequent decline, so a country that has peaked its emissions is demonstrating absolute decoupling if GDP continues to rise.

More recently, advocates have argued that the relationship between the growth of GDP and carbon dioxide needs to be cut completely. The International Energy Agency has highlighted measures that would enable this transition including phasing out fossil fuels, reducing methane emissions and scaling up financing for emerging and developing economies; proposals that were central to the discussions at COP28 in Dubai [3].

In 2022, global greenhouse gas emissions were approaching 54 billion tonnes (Gt) a year and slowly increasing [4]. Given that emissions in China are starting to flatline [5,6], and with emissions from the USA, Europe, and Japan already on a clear downward path, it is unlikely that future global GHG emissions will exceed 60 Gt a year. This maximum will be reached before 2030; after that time, global GHG emissions will almost certainly decline.

The emission mitigation scenarios presented by the Intergovernmental Panel on Climate Change (IPCC) that have a greater than 67 % probability of limiting global warming to 2C by mid-century show greenhouse gas emissions declining to approximately twenty billion tonnes of CO_2 equivalent (GtCO2e)[1] in 2050 [7].

[1] Carbon dioxide equivalent, CO2e, accounts for emissions of all greenhouse gases (not only carbon dioxide but also methane and nitrous oxide), and aggregates them into an equivalent quantity of carbon dioxide based on their respective global warming potentials.

Twenty gigatonnes of CO_2 equivalent is therefore the level of residual emissions that will have to be compensated by the carbon sinks and negative emission technologies in order to achieve the global balance between emissions and sinks that is the basis for the net zero emissions condition defined in the Paris Agreement [15]. This level of *natural* carbon absorption is certainly possible. According to the Global Carbon Project, over the period 2013-2022, ocean and land sinks absorbed carbon dioxide at a rate of 12.3 and 10.4 Gt/y, respectively [8].

One can therefore define the 2050 emission target: A 67 percent probability of keeping global warming to within 2 C, in terms of *per capita emissions of greenhouse gases.*

The United Nations Department of Economic and Social Affairs (UNDESA) estimates that the world population will be about 9.7 billion in 2050. [9] If the net zero emissions target is to be achieved, on a per capita basis average global emission of carbon will be approximately 20/9.7 = 2.1 tonnes of CO_2 equivalent. **This is the global average per capita GHG emissions target for 2050.**[2]

In 2022, greenhouse gas emissions were approximately 53.8 billion tonnes of CO2e a year [4], which for a population of close to eight billion people [10] gives **average per capita emissions of 6.8 tCO2e per year.** However, there are significant differences both between countries and among the different socio-economic groups within the countries themselves.

For example, per capita emissions in Canada and the US were both greater than 17 tCO2e/yr in 2022 [11]; more than eight times greater that the proposed global per capita target for 2050. Framed in this way, the idea of reducing per capita emissions to 2.1 tCO2e/y by 2050 seems unrealistic.

The European Green Deal

The European Climate Law wrote into law the goal set out in the European Green Deal, which states that Europe economy will become climate-neutral by 2050. The law sets an intermediate target of reducing net GHG emissions by at least 55% by 2030 compared to 1990 levels [12]. The EU27 countries produced approximately 4810 million tonnes of GHG emissions in 1990; per capita emissions were 11.5 tCO2e/y [11].

A 55 percent reduction by 2030 would drive emissions down to 2165 MtCO2e/y. The population of the EU in that year is estimated to be 449.1 million [10] and so per capita emissions, according to this scenario, would be approximately 4.8 tCO2e/y.

However, in February 2024, the European Commission recommended that Europe set a more stringent target of a *90 percent reduction in emissions by 2040* compared to 1990 levels [12,14].

This reduction will bring down emissions to 481 MtCO2e per year in 2040. The population of the EU that year is estimated to be about 446.8 million [13] and so per capita emissions, according to the scenario outlined in the European Green Deal, would be about 1.1 tCO2e in 2040, 52% below the 2050 global target of 2.1 tCO2e per capita. This is a very rapid rate of decline: amounting to a 10% reduction in GHG emissions annually over the period 2022 to 2040.

Post Net Zero

The countries that signed the 2015 Paris Agreement have committed to achieving a “balance between anthropogenic emissions by sources and removal by sinks of greenhouse gases in the second half of this century”, a condition generally referred to as ‘net zero emissions’ [15].

But what happens next? It is a reasonable assumption that countries do not intend to revert to the *status quo ex ante* after having achieved their goal of net zero emissions. That would make no sense. Nor is there any obligation for a country to introduce and maintain additional measures that enable the absorption by the natural sinks to exceed their remaining emissions. This logic implies that once countries achieve their goal of net zero emissions, they strive to maintain this condition but not necessarily to improve it. Under what circumstances is this sustainable steady-state possible, especially when GDP per capita and a country population are very probably still growing?

This study demonstrates first, that per capita GHG emissions can be reduced to a minimum level but not to zero. and second, a condition of global net zero emissions is feasible but to be sustained, economic growth must be constrained.

[2] 2 tCO2e would also be the ideal value of a person’s ‘carbon footprint’.

3. METHODOLOGY

To examine in detail the relationship between economic growth as denominated by GDP and emissions of GHGs, it is useful to recall the identity developed by energy economist Yoichi Kaya in 1993 [16]. Known as the Kaya identity, it formulates emissions of carbon dioxide as the product of the emission intensity of energy, the energy intensity of GDP, GDP per capita, and population. Although the factors cancel out (hence the term 'identity') the constituent elements are easily measured and analysed. It can be written as:

$$CO2 = \frac{CO2}{E} x \frac{E}{GDP} x \frac{GDP}{pop} x\ pop$$

where CO_2 is annual emissions of carbon dioxide; CO_2/E is the emission intensity of energy consumption; E/GDP is the energy intensity of GDP; and GDP/pop is per capita GDP.

Globally, both energy intensity and emission intensity have been decreasing, reflecting a widespread shift to renewable sources of energy, the increased efficiency of electrical energy compared to fossil fuels, and the electrification of key economic sectors. However, in most countries both GDP and population have continued to slowly rise; so, the question is: Can carbon emissions be held at a minimum level should GDP and population continue to trend upward?

To address this question a modified version of the Kaya identity will be employed: one that explicitly accounts for electrification and GHG emissions on a *per capita* basis. It can be written as:

$$\frac{CO2e}{pop} = \frac{CO2e}{elec} x \frac{elec}{E} x \frac{E}{GDP} x \frac{GDP}{pop}$$

Where,

- CO2e/pop is emissions of CO_2 equivalent per capita, tCO2e
- CO2e/elec is the total emissions of CO2e per unit of electricity generated, tCO2e/GWh
- elec/E is the electricity generated per unit of total energy consumption (both in GWh)
- E/GDP is the energy intensity of GDP, GWh/$GDP, where E is total energy consumption
- GDP/pop is per capita gross domestic product, $GDP/cap

In a sustainable steady-state of net zero emissions, the product of all four factors on the right-hand side of the identity has to be constant, and approximately equal to 2.1 tCO2e per capita, if the net zero condition is to be maintained.

The product of the first three factors can be called the *emission intensity factor*, EIF. Its value depends on the degree to which GHG emissions are reduced as fossil fuels are phased out (CO2e/elec); the level of electrification of the economy (elec/E); and the energy intensity of GDP. One can therefore state:

$$GHG\ emissions\ per\ capita\ = EIF\ x\ GDP\ per\ capita$$

Where,

$$EIF = \frac{CO2e}{elec} x \frac{elec}{E} x \frac{E}{GDP} \qquad tCO2e/\$GDP$$

In a country committed to reducing its carbon emissions, empirical data should show a clear decrease in the value of the emission intensity factor over time. In many countries, EIFs are falling. Globally, the metric declined from 730 gCO2e/$GDP in 1990 to 390 gCO2e/$GDP in 2022. In the European Union, the EIF declined from 400 to 160 gCO2e/$GDP over the same period.[3] Figure 1 shows how the EIF has declined in Europe over the last 30 years compared to the USA, UK and Canada [17].

[3] All GDP and GHG emission data discussed in this report are taken from the Our World in Data website. The GDP data are based on World Bank 2023 data, and expressed in "international dollars at 2017 prices adjusted for inflation and cost of living differences between countries." https://ourworldindata.org/grapher/gdp-per-capita-worldbank and https://ourworldindata.org/grapher/per-capita-ghg-emissions

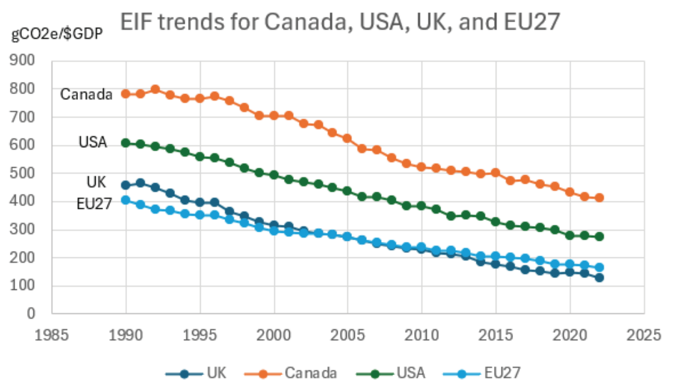


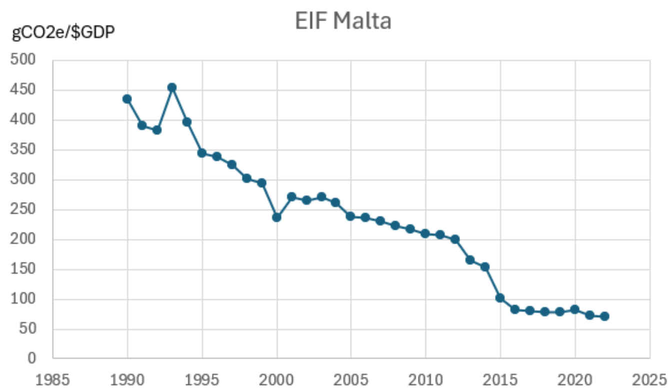
Fig. 1. EIF trends for Canada, USA, UK and Europe.

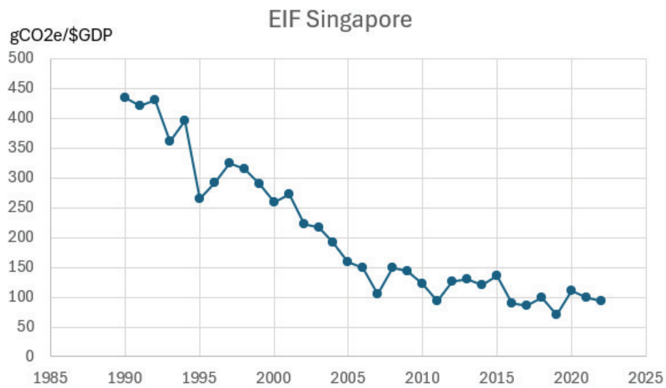
Emission intensity factors, gCO2e/$GDP, for Canada, USA, UK, and Europe from 1990 to 2022. EIF values have significantly declined in all regions: Canada by 47%; USA 55%; UK 72%, and EU27 by 60%. Source: https://ourworldindata.org/grapher/gdp-per-capita-worldbank and https://ourworldindata.org/grapher/per-capita-ghg-emissions.

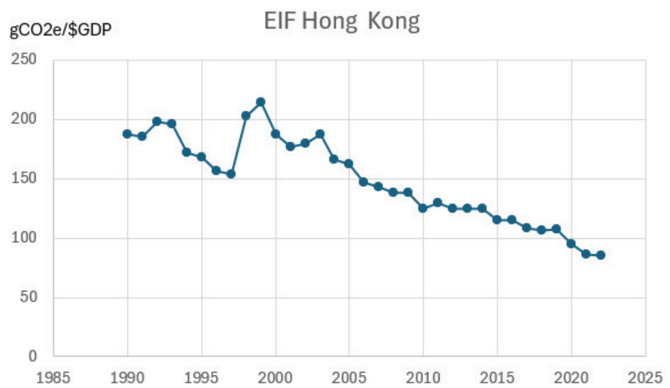
The three EIF components aggregate to the ratio of CO2e/GDP which is the reciprocal of the ratio that indicates the degree of decoupling. Even with a fully electrified economy powered by renewable sources of energy and operating at unprecedented efficiency, carbon emissions per dollar of GDP cannot fall to zero. GHG emissions come from agriculture, land use change, waste disposal, industrial processes, biogenic methane, and other sources unrelated to electricity generation. This implies that EIF will decline to a minimum value which it reaches asymptotically over time.

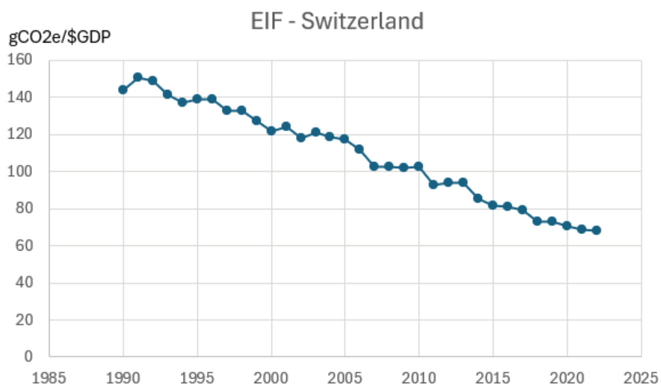
There is no clear indication in Figure 1 that the EIFs for the four countries shown decline asymptotically to a minimum value. This is because few countries approach this limit. However, the tendency can be seen in data from the five jurisdictions that had EIF values below 100 gCO2e/$GDP in 2022: Hong Kong, Malta, Singapore, Macao and Switzerland. The EIF downwards trend for these four countries and Macao is shown in Figure 2 [18].

For most governments, it is axiomatic that GDP must not only increase over time, but that the growth of GDP must exceed population growth, so that GDP per capita should continually rise. However, if per capita emissions are to be held at a level commensurate with net zero emissions, when the EIF declines to its minimum value, **GDP per capita must be held constant.** If not, the net zero emissions condition cannot be maintained and GHG emissions starts to rise.









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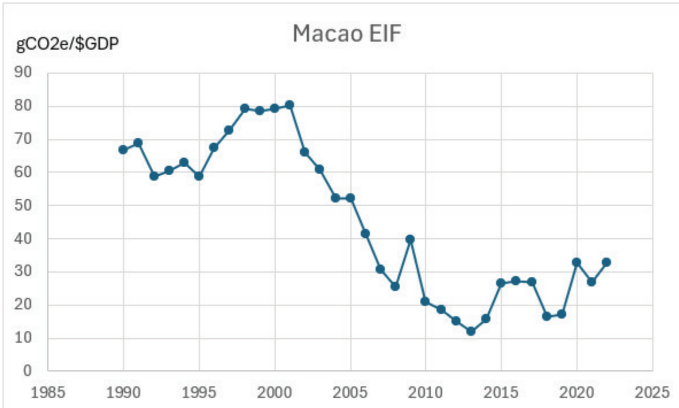

Fig. 2. Energy Intensity Factors for Malta, Singapore, Hong Kong, Switzerland, and Macao.

Emission intensity factors for Malta, Singapore, Hong Kong, Switzerland and Macao show a downward trend towards a theoretical minimum value. Analysis of the constituent factors of the EIF suggest that its value is unlikely to decline below 50 gCO2e/$GDP. Macao is an unusual case given its status as a 'special administrative region'. Source: https://ourworldindata.org/grapher/per-capita-ghg-emissions?tab=chart&country=HKG~MLT~MAC~SGP~CHE https://ourworldindata.org/grapher/gdp-per-capita-worldbank?tab=chart&country=HKG~MLT~MAC~CHE~SGP

The lower bound

It is crucial to estimate the lower bound of the emission intensity factor; the minimum value defines the lowest possible value of per capita GHG emissions for a specified per capita GDP.

Among the four countries and one region shown in Figure 2, Macao has the lowest EIF at 33 gCO2e/$GDP in 2022 (although it fell to 12 gCO2e/$GDP in 2013). But Macao is an unusual case. It is a 'special administrative region' of China; the most densely populated region in the world, with over 90 percent of its electricity imported from the mainland. More typical are the other four countries: where the lower bound for EIF appears to be between 50 and 70 gCO2e/$GDP. Given that the EIF values are still slowly declining in the four countries showcased, for the purpose of the following discussion the researcher assumes that the lower bound on the emission intensity factor, $EIF_{min,}$ is closer to 50 gCO2e/$GDP.

The theoretical minimum for a country GHG emissions per capita can be calculated from this value. **It is simply equal to EIF_{min} x GDP per capita.**

The EIF_{min} is not a 'universal' constant. Every country minimum EIF is slightly different because all economies have different structural and socio-economic characteristics; but there is a universal rule: **the value of the EIF tends to a minimum.**[4]

Note that the countries shown in Figure 2 are all modern economies with per capita GDP values over $50,000. Low-income countries do not have low EIFs. Although their emissions may be minimal, GDP per capita is also very low. For example, the average EIF for low-income and lower middle-income countries is 1420 and 420 gCO2e/$GDP, respectively.

If GDP per capita is to be held constant from mid-century, this does not mean that the economic growth of low-income countries is impeded or curtailed. On the contrary, if their EIF is reduced to a minimum, the per capita emissions target of approximately 2 tCO2e allows for a developing country per capita GDP to rise to $40,000, about the same level as Spain, and greater than Italy, Poland, and Portugal [18].

The per capita GDP of all low-income developing countries could theoretically rise to this level by mid-century--if they introduce policies that reduce EIF to a minimum of approximately 50 gCO2e/$GDP. Few low-income countries may achieve this target; but nothing in the transition to a global condition of sustainable steady-state emissions at a level of 2 tCO2e per capita by 2050 prevents this scenario from becoming possible. In reality, the required rates of economic growth are very high: the GDP per capita of low-income countries would need to increase at 11.4% a year to reach $40,000 in 2050; while for lower middle-income countries, the required annual rate of growth is 6.4 %.

[4] Strictly speaking: a non-zero positive value.

These growth rates are challenging but not impossible; for example, annual GDP growth in China averaged 7.8% from 2000 to 2022 [18].

Minimising the EIF

The Emission Intensity Factor can be disaggregated into three components, each of which should be the focus of a specific and targeted set of energy policies. In many countries, the value of EIF is slowly declining, but measures to accelerate its decline are essential if values close to 50gCO2e/$GDP are to be achieved before mid-century.

1. **The component, *CO2e/elec,*** is substantially reduced by phasing out all fossil-fuel electricity generation ideally before 2030. The generation of electrical power must not produce *any* emissions of carbon; which means that all generation is from renewable sources of energy: primarily hydropower, solar energy and wind power (but not biomass). Other renewable sources such as geothermal energy may also become more important over the next 25 years. Nuclear power is also carbon-free and some countries will undoubtedly invest in this technology despite its abysmal track record in terms of cost overruns, lengthy construction delays, and the still intractable problem of radioactive waste management. [19, 20] This component cannot decline to zero. In all modern economies, there are diffuse emissions of carbon dioxide, methane, and nitrous oxide from biogenic sources, and these cannot be entirely eliminated. The Our World In Data (OWID) database shows six countries with values below 100 gCO2/kWh (Iceland, Norway, Macao, Malta, Singapore and Sweden) with an arithmetic mean of 61 gCO2/kWh [18]. The other GHGs raise this value by about 20 percent, so the minimum value for this component may be estimated as approximately 73 gCO2e/kWh.

2. **The degree of electrification, *elec/E,*** is a ratio that approaches unity as economic activity becomes increasingly electrified. Policies should initially focus on the transport and building sectors. But progress will be slow (as it is now) unless governments incentivise, *inter alia,* the transition to electric vehicles and the electrification of heating and cooling systems in buildings and industry by the deployment of heat pumps. The electrification of steel-making and other heavy industry is essential, as is the production of industrial-scale electrolytic hydrogen powered by renewables. Aviation and marine transportation are responsible for a significant percentage of global GHG emissions, and these sectors will either electrify or operate on carbon-neutral biofuels.

3. **The energy intensity of GDP, *E/GDP,*** is a measure of the efficiency of economic activity as measured by GDP. Its value declines with the improved energy efficiency of buildings and transport, decarbonisation, and electrification. The minimum value among high-income countries (for example Switzerland) is 0.52 kWh/$GDP [18].

The values of the EIF components referenced above lead to an estimate of EIF_{min} of approximately 37 gCO2e/$GDP. But this value is only theoretically possible if each of the EIF components are reduced to their absolute minimum. Setting a target of 50gCO2e/$GDP is more realistic, and one that has already been achieved in at least one jurisdiction: Macao.

4. RESULTS AND DISCUSSION

For the countries of EU27, population growth is forecast to be close to zero up to mid-century and then to slowly *decline* at 0.13% per year [13]. In 2022, per capita emissions had declined to 7.5 tCO2e, but GDP per capita was still rising at about 1.3% a year.

A constantly increasing GDP per capita will fatally undermine European emission targets no matter how forceful the transition to fully electrified, highly energy-efficient economies is. For example, at current rates of 1.3 % a year, EU27 GDP per capita will reach $67,000 in 2050, at which time per capita emissions at an EIF_{min} of 50gCO2e/$GDP will be 3.3 tCO2e, well short of the target aimed at limiting global temperatures to its less stringent value.

Similarly, in the case of the United States, at current rates of growth, GDP per capita will rise to $93,352 by 2050. Even if the EIF falls to 50 gCO2e/$GDP, per capita emissions will be about 4.7 tCO2e/y, more than twice the value of the global target.

This analysis shows that for developed countries with per capita GDPs above $40,000, policies aimed at achieving compliance with the Paris Agreement target by mid-century must confront an unpalatable truth: **Compliance is impossible if GDP per capita is allowed to constantly rise.**

Many developing countries face no such constraints. Nigeria, for instance, forecasts an annual population growth of 2.4 % through to 2050 which means that the country economy could grow at this rate if it maintains its currently low level of emissions at approximately 2 tCO2e per capita [21].

China, which alone accounts for a quarter of global GHG emissions, has nonetheless reduced its EIF from 1130 gCO2e/$GDP in 2000 to 540 gCO2e/$GDP in 2022. It has a long way to go; but the pace of the transition to renewable sources of energy is extraordinary: 180 GW of utility-scale solar and 159 GW of wind power are currently under construction, twice as much as the rest of the world combined [22]. However, the country has also constructed new coal-fired power plants, often as back-up for variable solar energy and wind power. Longer term, pumped hydropower storage may be the key to phasing out coal and reducing per capita emissions--which in 2022 were 9.8 tCO2e/y [18].

The preceding argument confirms that the concept of an absolute decoupling of economic growth and emissions which would allow for unrestrained growth is not plausible. In such a scenario, the ratio of GDP to carbon emissions would continue to increase indefinitely. However, as we have noted, the ratio of $GDP to gCO2e is the reciprocal of the Emission Intensity Factor--which has a lower bound of approximately 50 gCO2e/$GDP. We may therefore deduce that the ratio of GDP to carbon emissions is limited by an upper bound of approximately 20 $GDP/kgCO2e. Economic growth can never be fully decoupled from carbon emissions. The ratio can be substantially increased but it is limited by an upper bound.

Negative Emission Technologies

The technologies that could potentially change this pessimistic forecast are the so-called negative emission technologies (NETs). These technologies absorb carbon dioxide from the atmosphere and lock the carbon away in a variety of substrates: biomass, seawater, and geologic formations[5]. In principle, if these technologies can withdraw substantial amounts of carbon dioxide from the atmosphere, this would allow for a higher level of emissions than the 20 GtCO2e target judged to be necessary by the IPCC for limiting global temperatures to 2C above pre-industrial levels by 2050.

The most comprehensive evaluation of NETs was conducted by the Science Advisory Council of the European Academies in 2018 [24]. The EASAC evaluated seven NETs: afforestation and reforestation; land management to increase soil carbon; bioenergy with carbon capture and storage (BECCS); enhanced weathering; direct air capture and carbon storage (DACCS); ocean fertilisation; and carbon capture and storage.

The report is not encouraging. The EASAC concludes that "*these technologies offer only limited realistic potential to remove carbon from the atmosphere and not at the scale envisaged in some climate scenarios (as much as several billion tonnes of carbon each year post 2050). Negative emission technologies may have a useful role to play but, based on current information, not at the level required to compensate for inadequate mitigation measures"[23].*

The Science Advisory Council went on to say "*Scenarios and projections of NET's future contribution to CDR (carbon dioxide removal) that allow Paris targets to be met thus appear optimistic on the basis of current knowledge and should not form the basis of developing, analysing and comparing scenarios of longer-term energy pathways for the European Union."*

More recent reports on BECCS and carbon capture and storage technologies have confirmed this negative assessment [25]. Moreover, the contribution of forests, previously thought to be reliably effective as carbon sinks, has been called into question by the way rising global temperatures have provoked a greater frequency of increasingly intense and destructive wildfires. Many forested regions are now carbon *sources* not carbon *sinks* [25, 26].

[5] How long the carbon is locked away depends on the technology. Carbon stored in biomass is sequestered for several decades, whereas carbon fixed chemically in seawater and geologic strata is held longer in the 'slow' carbon cycle. Carbon dioxide stored underground is in principle permanently sequestered—assuming the storage system doesn't leak.

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This realistic assessment of the limitations of negative emission technologies leads to the conclusion that measures to *directly reduce greenhouse gas emissions* must be the foundation of all country policies aimed at limiting global temperatures to less than 2C above pre-industrial levels.

Increasing Population

The questions remains whether global steady-state emissions of around 2 tCO2e *per capita* will hold *total* emissions at a level commensurate with the Paris accords. In other words, sustainable per capita emissions may be a *necessary* condition but not necessarily a *sufficient* one.

The UN Department of Economic and Social Affairs projects that the world population is likely to peak within the current century. The 2024 population of 8.2 billion is forecast to grow to about 10.3 billion people in the mid-2080s, before gradually declining to 10.2 billion by the of the century [9]. The annual rate of increase over the period to the mid-1980s is only 0.38 percent.

Recall that the global target for GHG emissions in 2050 is 20 GtCO2e. Global emissions may therefore rise to 21.2 GtCO2e by the mid-2080s before declining slightly to 21.0 GtCO2e by the end of the century. These projected minor increases in global emissions after mid-century are inconsequential compared to the significant challenge of reducing total emissions from the current level of approximately 54 GtCO2e to 20 GtCO2e by 2050.

If the target of reducing global emissions in line with the Paris Agreement is redefined as maintaining annual GHG emissions post-2050 at 20 tCO2e (±1 tCO2e), the requirement of steady-state *per capita* emissions becomes a *sufficient* condition.

Emission Inequality

The linear relationship between per capita emissions and per capita GDP enables a new perspective on the latter metric which can now be disaggregated over a range of demographic cohorts. The work of Lucas Chancel has highlighted the substantial difference in per capita GHG emissions across population cohorts in several regions of the world [27, 28]. Figure 3 shows per capita emissions in Europe and the USA for three population groups: the bottom 50%; the middle 40%, and the top 10% of the income distribution.

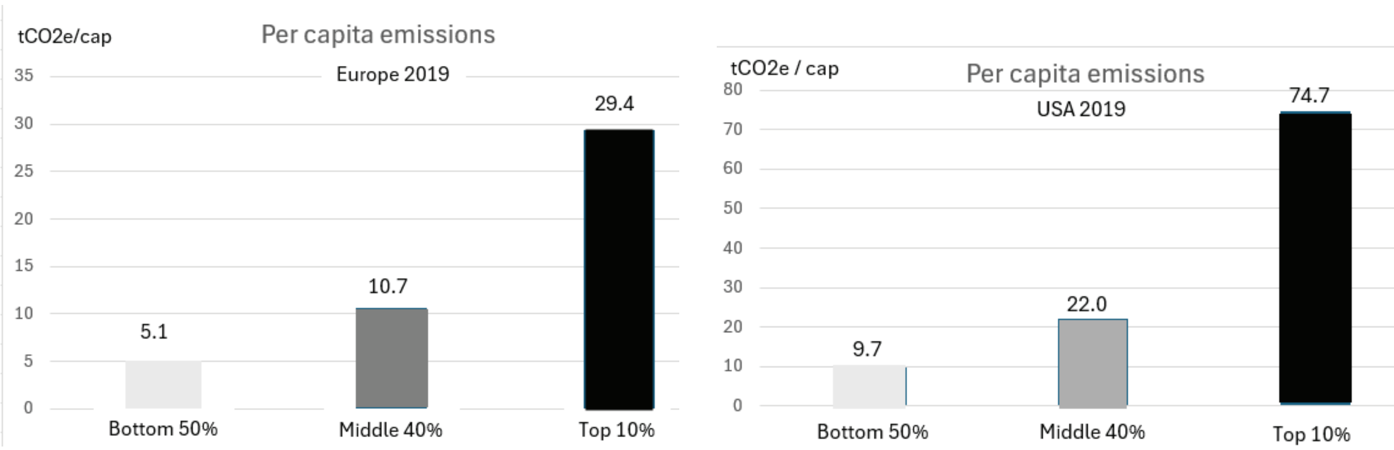

Fig. 3. Emission inequality in Europe and USA.

Per capita GHG emissions from the top 10% of the income distribution in Europe and the USA are roughly 6 to 7 times higher than the bottom 50%. The middle 40% also emits twice as much per capita as the bottom 50%. Source: Chancel, L. Global carbon inequality over 1990-2019. [24] and World Inequality Report 2022 [28].

It is notable that the top ten percent of the income distribution in Europe emits almost 6 times more greenhouse gases than the bottom 50 percent and almost 3 times more than the middle 40 percent on a per capita basis. In the USA, the inequality in per capita emissions is even more pronounced. In sum, the top ten percent are responsible for 30 percent of all greenhouse gas emissions in Europe and 35

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percent in the USA. This emission inequality is seen in every region analysed by Chancel [27], and points to the need to reduce emissions by focusing specific mitigation policies on each demographic cohort and particularly on the top 10 percent of the income distribution.

These data enable one to calculate Emission Intensity Factors for Europe and the USA from per capita GDP and per capita GHG data [17].

Table 1: Emission and GDP data for EU27 and USA (2019)

	EU27	USA
GDP per capita, $GDP/cap	$44,371	$64,623
Emissions per capita, tCO2e/cap	9.77	21.12
Emission Intensity Factor, gCO2e/$GDP	220	327

GDP per capita can now be calculated for each population group. The results are shown in Figure 4.

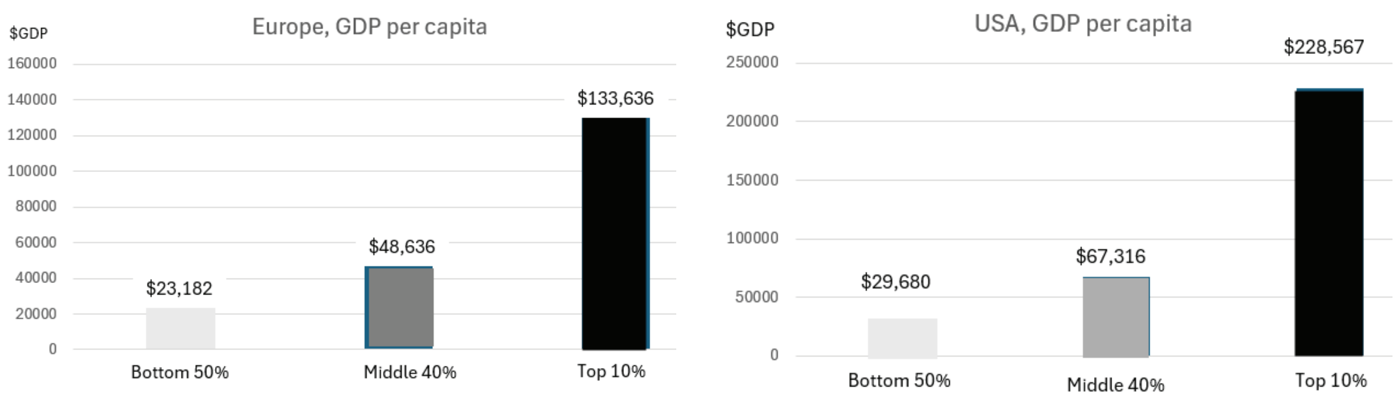

Fig. 4. Per capita GDP per demographic cohort in Europe and USA (2019).

Per capita GDP values mirror per capita emissions because of the linear relationship between the two variables. Based on EIF=220 gCO2e/$GDP for Europe and 327 gCO2e/$GDP for USA.

Figure 4 underscores the fact that the top 10 percent of the distribution are responsible for a disproportionate amount of the economic and environmental impacts of GDP growth: 30 percent in Europe and 35 percent in USA.[6]

The condition for sustainable net zero emissions depends first, on reducing the emission intensity factor, EIF, to its minimum value--which the researcher has estimated as being close to 50 gCO2e/$GDP; and second, on reducing per capita GDP to approximately $40,000. Under these conditions, per capita emissions can be held at approximately 2.1 tCO2e/yr which is the global target for holding rising temperatures to no more than 2 C above pre-industrial levels from 2050 onwards.

It is instructive to examine the impact of these conditions on the structure of disaggregated GDP. Figure 5 shows the per capita GDP threshold of $40,000 in relation to 2019 values for each cohort for Europe and USA.

[6] Based on the *total* GDP for each cohort, equal to population x per capita GDP.

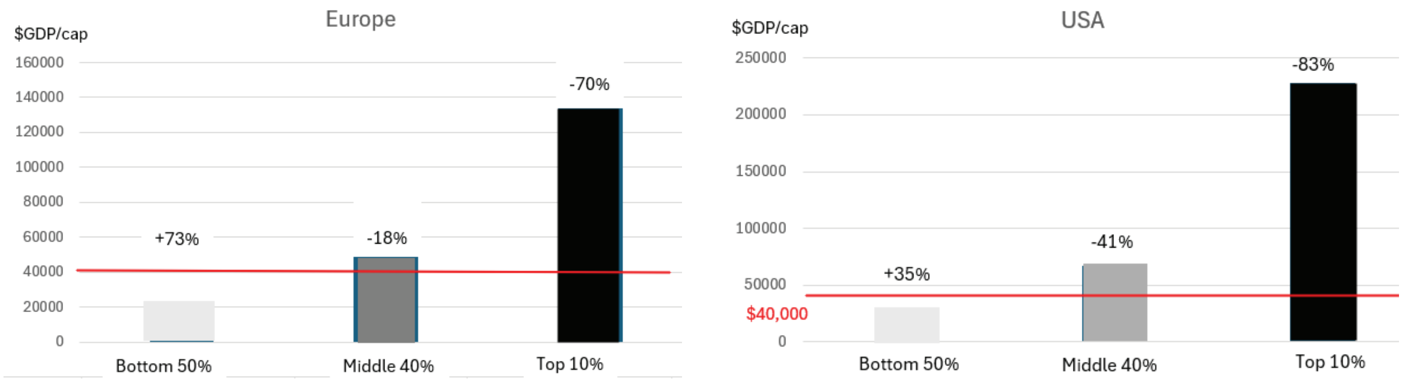

Fig. 5. Changes in per capita GDP at net zero emissions.

If the EIF is reduced to its minimum value, the bottom 50% of the income distribution in Europe and the USA may increase their per capita GDP to the target level of $40,000. Modest reductions in GDP per capita are required of those in the middle 50%. However, substantial reductions in per capita GDP are required of the top 10%.

If per capita GDP is to be held at $40,000 across all cohorts, in Europe these changes would amount to a 72.4% *increase* in the per capita GDP of the bottom 50%; a *reduction* of 18% in the per capita GDP of the middle 40%; and a *reduction* of 70% in the per capita GDP of the top ten percent. In the USA, the bottom 50% can still grow their economies by one third. But the middle 50% see a reduction of 41 percent, and the top 10% are looking at a reduction in per capita GDP of more than 80 percent if the US is to reduce its emissions to a level commensurate with the Paris Agreement target.

National emission-reduction policies should therefore focus primarily on the top 10 percent of the population. The paper by Chancel [27] discusses one such option which is the imposition of a tax on investments proportional to their carbon content. According to his estimates, such a tax would impact close to 100% of the top 10% of the global population, but the bottom 77% of the US population and the bottom 90% of the European population would be unaffected. Other fiscal instruments are likely to be necessary, but the essential point is that government policies to reduce GHG emissions should take account of the inequality of emissions in order to better target the economic and environmental impacts of their policies.

How these redistributive measures are to be designed and implemented is beyond the scope of this paper. A comprehensive review of the theory and practice can be found in the works of Picketty [29].

5. INTERNATIONAL CONTEXT AND RELEVANCE

At the 2023 European 'Beyond Growth' conference, the post-conference declaration (signed by over 1180 participants) agreed to set a pathway to a "post-growth" world in which the economy and society would "thrive while operating within the established planetary limits" [30]. One of these limits is the atmospheric concentration of carbon dioxide [31].

The 'beyond growth' scenarios include **Green/ inclusive growth**, where growth is still a central policy, but adjustments are made to ensure sustainability and inclusivity; **Degrowth,** which takes an opposing view and envisions a steady-state or shrinking economy; and **post-growth**, which is agnostic about growth, instead focusing on a "more rounded vision of social and economic progress" [32].

It is axiomatic in all three scenarios that planetary limits should not be breached--which means that **a condition of net zero emissions at approximately 2 tCO2e per capita must be achieved and maintained.**

If there is to be a realistic possibility of keeping global temperatures from exceeding 2 C above pre-industrial levels, all countries must design and implement measures to reduce the value of their *emission intensity factors* to the minimum level of approximately 50 gCO2e/$GDP. These measures include the complete phase-out of fossil fuels; the electrification of all sectors of the economy; and the reduction of the energy intensity of GDP by *inter alia* investing in more efficient and less carbon-intensive industrial processes and by taking stronger steps towards an economy with much lower rates of extraction, consumption, and waste.

Low-income and developing countries should also follow these energy and industrial policies. They may continue to grow their economies, but in a way that limits greenhouse gas emissions to the greatest possible extent. Higher levels of electrification based on rural mini grid systems are essential and all forms of transport should be electrified. Also essential is the transition away from biomass fuels used for cooking. The analysis set out in this paper suggests that GDP per capita should not rise above $40,000 a year, a level approximately the same as Spain. This strategy provides considerable GDP headroom for low- and middle-income countries which have average per capita GDPs below $5000 and $20,000 respectively [18].

High-income countries face a highly consequential choice, with implications of global even existential importance. They can continue to grow their economies; or they can decelerate and curb economic growth and reduce their emissions to a sustainable steady-state aligned with Paris Agreement targets. But they cannot do both.

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