TEMASEK ecosperity

PATHWAYS TO A LOW-CARBON FUTURE: DECOUPLING ECONOMIC GROWTH FROM CARBON EMISSIONS

Discussion Paper

Sep 2019

PATHWAYS TO A LOW-CARBON FUTURE: KEY TAKEAWAYS

1. **185 parties** have ratified the Paris Agreement to limit global temperature rise to 2°C. They have also committed to an aspirational target of 1.5°C.

2. **The world does not appear to be on track to achieve these targets.** Under the current trajectory, global carbon emissions are set to be **double of that required for a 1.5°C pathway.**

3. Differences in factors such as **population size, economic structure and embedded emissions** render it difficult to compare carbon emissions across countries.

4. **It is possible to decouple GDP from carbon emissions.** Since 2010, **41 percent** of countries have grown their economies faster than their increase in carbon emissions while **16 percent** have grown without increasing carbon emissions.

5. Decoupling can be attributed to a number of factors such as changes in a country's **economic structure, a shift in energy mix towards renewable sources and improvements in energy efficiency.**

6. There are large **differences across countries in terms of resource efficiency** and governments can adopt best practices from each other.

7. In Asia, it is estimated that there are **US$3.1 trillion worth** of business opportunities associated with increased carbon productivity.

8. Consumers can reduce their overall carbon footprint by up to **85 percent through a range of individual actions.**

PATHWAYS TO A LOW-CARBON FUTURE

There is growing consensus on the urgent need to curb global greenhouse gas (GHG) emissions, of which carbon dioxide (CO_2) is a key contributor. Many countries are committed to reducing carbon emissions and there are on-going efforts to rank their emission contributions. However, comparing CO_2 emissions on an absolute basis across countries can be challenging due to differences such as population size, economic structure and embedded emissions on top of measurement issues.

This paper, prepared in collaboration with AlphaBeta, discusses the potential challenges and insights arising from a comparison of emissions across countries. For example, while economic growth is typically linked to increased energy consumption, it can be decoupled from carbon emissions if measures such as energy efficiency are implemented, renewable energy sources are tapped, or more fundamentally, the economy is structured towards having a greater share of services or advanced manufacturing. Collective action is also required from governments, businesses and consumers to achieve a low-carbon future.

1. Countries are committed to reducing GHG emissions, but progress seems to be lagging

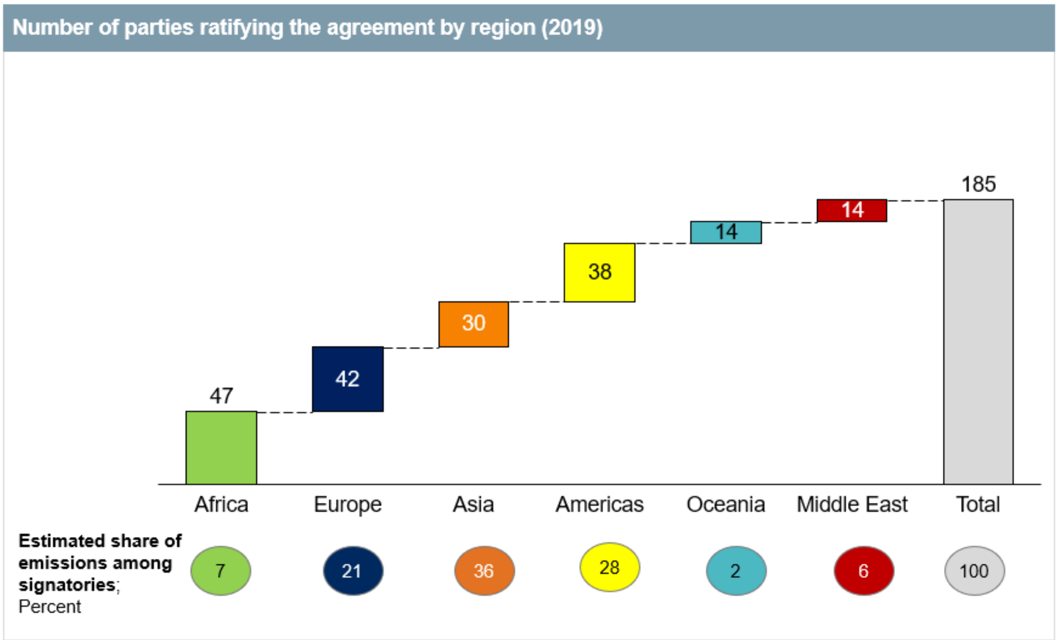
Under the Paris Agreement, 185 parties[1] have agreed to take action and keep global temperature rise within 2°C above pre-industrial levels, with an aspirational target to limit this increase to 1.5°C (Exhibit 1).[2] According to the Intergovernmental Panel on Climate Change (IPCC), the 1.5°C pathway would require a 45% reduction in annual carbon emissions from 2010 levels by 2030, and net zero[3] emissions by 2050. Even limiting warming to 2°C would require a 25% reduction in annual emissions from 2010 levels by 2030.

However, the world does not appear to be on track. Under the current trajectory, global emissions are set to be double of that required for a 1.5°C pathway (Exhibit 2).

[1] 184 states and the European Union have ratified the Paris Agreement.
[2] Sources include: United Nations Framework Convention on Climate Change [UNFCCC] (2018), *The Paris Agreement.* Available at: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
UNFCCC (2019), "Paris Agreement - Status of Ratification". Available at: https://unfccc.int/process/the-paris-agreement/status-of-ratification
[3] Net zero emissions are achieved when anthropogenic emissions are balanced globally by anthropogenic removals over a specified period.

EXHIBIT 1

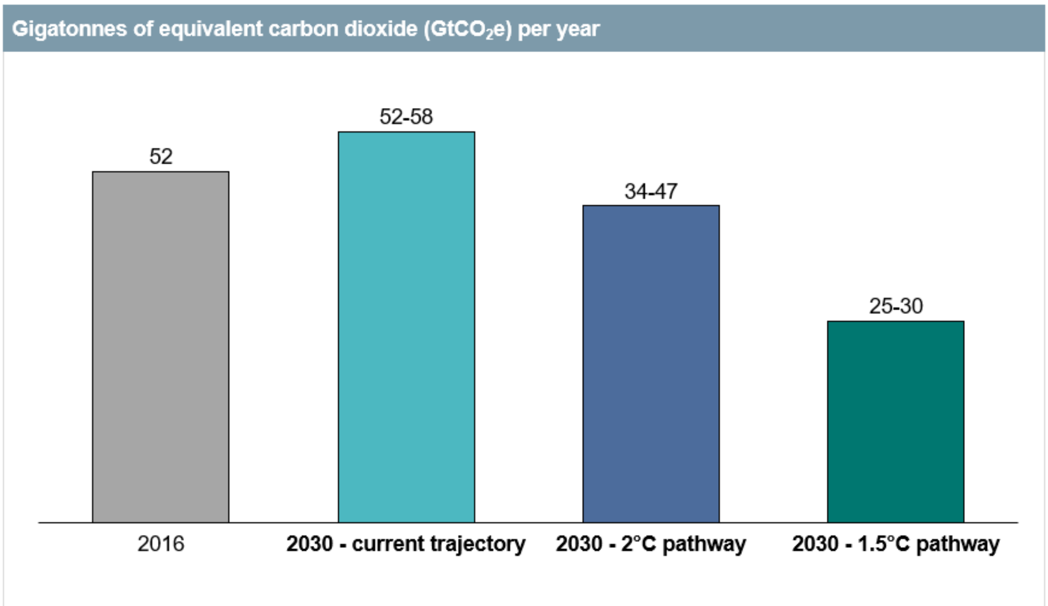
185 parties (covering almost 90 percent of global emissions) have ratified the Paris Agreement to date



SOURCE: United Nations Framework Convention on Climate Change (UNFCCC)

EXHIBIT 2

The world does not appear to be on track to limit temperature rise to 1.5°C by the end of the century



SOURCE: IPCC; AlphaBeta analysis, Climate Action Tracker

A key challenge to realising emission targets is balancing economic development with climate change mitigation. Studies have shown that climate change can cause significant long-term adverse impacts on economies. For example, flooding from rising sea levels could cost the world economy up to US$27 trillion annually by 2100, if we do not limit warming to 1.5°C.[4]

Global warming could also cost the world economy over US$2 trillion in lost productivity by 2030.[5] According to the IPCC, the adverse impact of temperature rises will be significantly higher at 2°C than at 1.5°C.[6]

2. Measuring country-level performance in carbon emissions will be important to track global progress

GHG emissions include carbon dioxide, nitrous oxide, methane and fluorinated gases (e.g. HFCs, PFCs). This paper focuses on carbon dioxide released from human activities, which accounts for over three-quarters of GHG emissions globally.[7] From 2024, countries will be required to report national-level GHG data. Measuring carbon productivity will thus be important to ensure that the world is on track to meet our collective carbon goals.[8]

Information on the emission contributions of countries can be accessed through various tools online:

- **Global Carbon Atlas** is a platform to explore and visualise data on carbon fluxes resulting from human activities and natural processes.[9]

- **Climate Watch** brings together datasets to let users analyse and compare the Nationally Determined Contributions (NDCs) under the Paris Agreement, access historical emissions data, discover how countries can leverage their climate goals to achieve sustainable development objectives, and use models to map new pathways to a low carbon future.[10]

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[4] S. Jevrejeva, A. Grinsted and J.C. Moore (2018), "Flood damage costs under the sea level rise with warming of 1.5 °C and 2 °C", Environment Research Letters. Available at: http://iopscience.iop.org/article/10.1088/1748-9326/aacc76/pdf
[5] VOA (2016), "Global Warming to Cost $2 Trillion in Lost Productivity by 2030". Available at: https://www.voanews.com/a/global-warming-cost-two-trillion-dollars-lost-productivity/3424781.html
[6] Intergovernmental Panel on Climate Change (2018), *Special Report - Global Warming of 1.5ºC.* Available at: https://www.ipcc.ch/sr15/
[7] *Centre for Climate and Energy Solutions*. Accessed at: https://www.c2es.org/content/international-emissions/
[8] Carbon Brief (December 2018), "COP24: Key outcomes agreed at the UN climate talks in Katowice". Accessed at: https://www.carbonbrief.org/cop24-key-outcomes-agreed-at-the-un-climate-talks-in-katowice
[9] Accessed at: http://www.globalcarbonatlas.org/en/content/welcome-carbon-atlas
[10] Accessed at: https://www.climatewatchdata.org/

- **Our World in Data** brings together data and research on major global trends, including carbon emissions.[11]

- **Climate Action Tracker (CAT)** is an independent scientific analysis produced by three research organisations which have been tracking climate action since 2009.[12]

3. Comparing country-level performance is not straightforward due to various factors

> Comparing per capita emissions may not be effective due to large population differences across countries

It is recognised that comparing countries based on absolute amounts of CO_2 emitted is difficult. For example, Tuvalu has a population of just 11,190 whereas China has a population of over 1.4 billion. It would therefore not be meaningful to compare the total emissions of these two countries.[13] Adjusting for various economic and demographic indicators such as Gross Domestic Product (GDP) and population size to compare more effectively may also be challenging due to factors such as:

- **Economic structure.** A country's economic structure can have important implications for CO_2 emissions, and this could also vary by the stage of economic development. In general, the manufacturing sector is more CO_2 intensive per dollar of economic output compared to the service sector. Manufacturing in the United States was estimated to be two to three times more carbon and energy intensive than services provision.[14] Given that the manufacturing sector is key in many developing countries, this may lead to higher CO_2 footprints. The carbon emissions intensity of advanced high-tech manufacturing however could be much less.

- **Embedded emissions.** Under past climate change agreements such as the Kyoto Protocol, a country's commitment to reduce emissions does not take into account emissions attributable to their imports, known as 'embedded (or embodied) emissions' of goods. Embedded emissions are instead attributed to exporting countries, raising important issues around equity. For example, approximately 22% of all CO_2 emissions from human activities 'flow' (i.e. are imported or exported) from one country to another.[15] As a result, carbon emissions are generally viewed to be underestimated for developed countries and

[11] Accessed at: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions
[12] Accessed at: https://climateactiontracker.org/
[13] Tuvalu and China population as of 2017
World Bank (2017). Available at: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=TV-CN
[14] Timothy G. Gutowski (2007). "The Carbon and Energy Intensity of Manufacturing". Available at: http://web.mit.edu/ebm/www/Publications/Carbon%20Intensity%20of%20Manufacturing.pdf
[15] G. P. Peters, S. J. Davis, and R. Andrew (23 August 2012), "A synthesis of carbon in international trade", *Biogeosciences*, 9, 3247–3276, 2012. Accessed at: https://www.biogeosciences.net/9/3247/2012/bg-9-3247-2012.pdf

overestimated for developing countries (where most primary manufacturing takes place). For example, OECD countries are found to be significant net-importers of embodied carbon.[16]

- **Climate.** The geographical location of a country determines its climate and consequently its heating and cooling needs. One approach to incorporate local climate into emissions rankings would be subtracting emissions caused by heating and cooling. Adjusting for the total number of heating and cooling degree days has been found to have important implications for comparing emissions across countries.[17]

- **Measurement issues.** There are several challenges in measuring carbon emissions. First, emissions can be measured using fossil fuel consumption data at country level, but data availability and accuracy vary largely across countries. For example, coal consumption was underestimated by up to 15 percent between 2005 and 2013 in China, resulting in about one billion tonnes of CO_2 emissions per year being unaccounted for.[18] Second, emissions from human activities are often entangled with nature's fluctuating carbon cycle. For instance, Canada's forests were carbon sources instead of sinks in some years over the past decades. Incidents such as wildfires led to the release of more atmospheric carbon than what was absorbed in that year.[19]

  Additional adjustments for economic and demographic factors can involve measurement issues as well. For example, measuring GDP based on purchasing power parity (PPP) (which adjusts for local purchasing power of incomes) can result in measurement errors. In China, PPP-adjusted per capita GDP was reduced by 40 percent in 2005 due to new survey data which showed higher than expected prices. This figure was then reversed by new price data in 2011.[20] Therefore, comparing carbon emissions against GDP, GDP per capita or PPP-adjusted GDP per capita can be complicated by cyclical fluctuations, and may provide an incomplete picture on long-term carbon productivity trends.[21]

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[16] OECD (2019), "Carbon dioxide emissions embodied in international trade". Accessed at: http://www.oecd.org/sti/ind/carbondioxideemissionsembodiedininternationaltrade.htm

[17] Michael Siwak and Brandon Schoettle (2012), "Accounting for Climate in Ranking Countries' Carbon Dioxide Emissions", *American Scientist*, Volume 100, Number 4. Available at: https://www.americanscientist.org/article/accounting-for-climate-in-ranking-countries-carbon-dioxide-emissions

[18] The New York Times (2015), "China Burns Much More Coal Than Reported, Complicating Climate Talks". Available at: https://www.nytimes.com/2015/11/04/world/asia/china-burns-much-more-coal-than-reported-complicating-climate-talks.html

[19] Natural Resources Canada (2016), "Forest carbon". Available at: https://www.nrcan.gc.ca/forests/climate-change/forest-carbon/13085

[20] CP Changra Sekar and Jayati Ghosh (2017), "Problems with using PPP-based exchange rates", The Hindu Businessline. Available at: https://www.thehindubusinessline.com/opinion/columns/problems-with-using-pppbased-exchange-rates/article9981788.ece

[21] IMF (2018), *The Long-Run Decoupling of Emissions and Output: Evidence from the Largest Emitters.* Available at: https://www.imf.org/en/Publications/WP/Issues/2018/03/13/The-Long-Run-Decoupling-of-Emissions-and-Output-Evidence-from-the-Largest-Emitters-45688

4. Despite the challenges to comparison, insights can still be gleaned by using multiple indicators to analyse data

While these challenges are important caveats for a simple comparison of country emissions adjusted for GDP and population size, there are still insights to be gleaned from comparing emissions using multiple indicators. This research focuses on three of them:

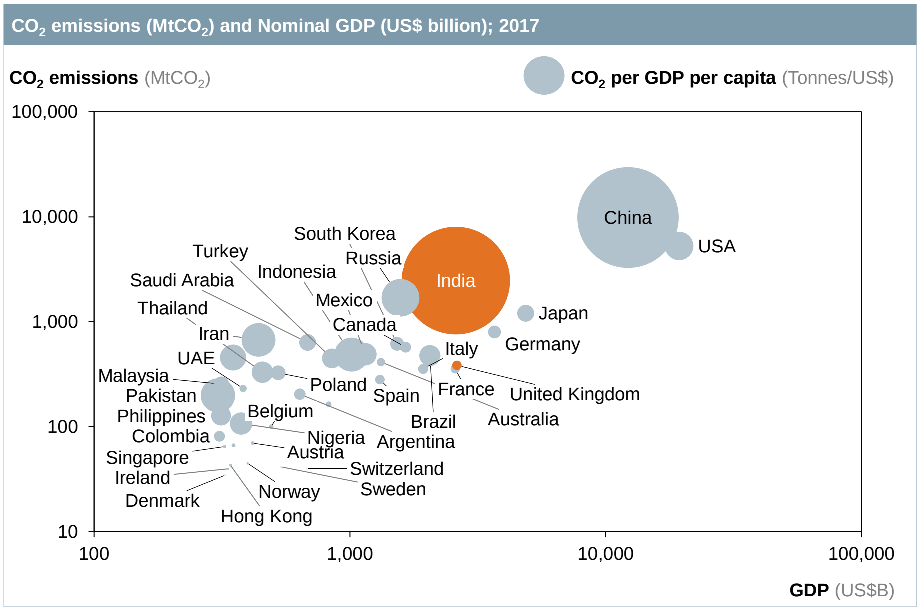
- **GDP-adjusted.** Comparing absolute carbon emissions against the size of the economy.
- **Population-adjusted.** Comparing absolute carbon emissions against population size.
- **Income-adjusted.** Comparing per capita emissions, adjusted for average incomes.

Initial observations made when analysing data across multiple indicators include:

- **Countries with similar GDP or population sizes can have different carbon emission profiles based on their economic structures.** CO_2 emissions generally increase with GDP (Exhibit 3). Based on absolute emissions, China, the United States, India, Russia and Japan are the top five largest emitters. Of the 10 largest economies in the world, 60 percent are also among the 10 largest emitters. However, deviations exist – CO_2 emissions can vary significantly among countries with similar GDP. For example, despite having similar GDP, India emits six times more CO_2 than the UK. CO_2 generated per dollar of GDP per capita also differs significantly between the two countries (Exhibit 3).

EXHIBIT 3

CO_2 emissions generally increase with GDP

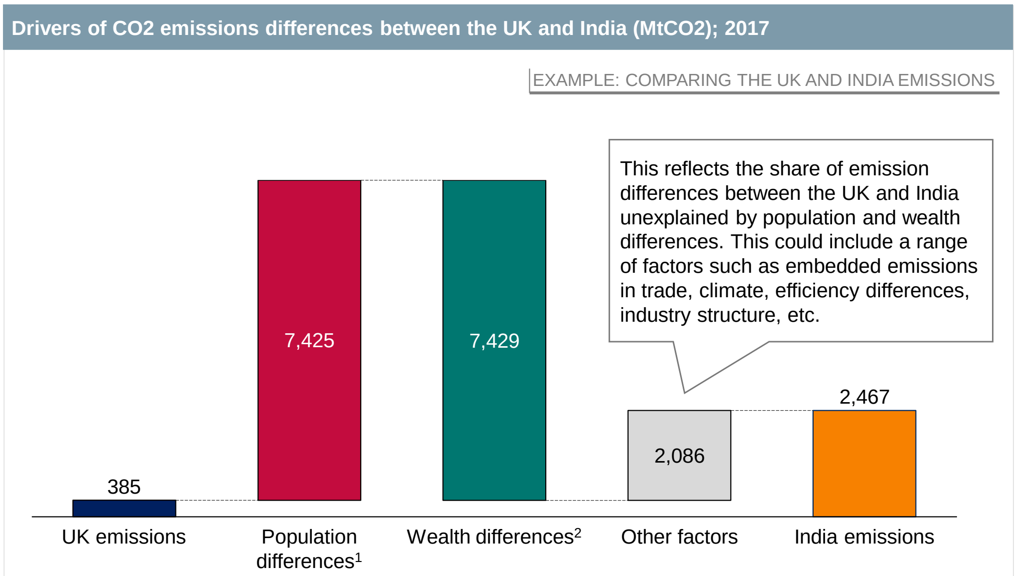


SOURCE: Global Carbon Atlas; World Bank

- **Population and wealth differences can only partly account for differences in carbon emissions.** As shown in Exhibit 4, the effect of population differences between the UK and India is mostly counterbalanced by their wealth differences (i.e. GDP per capita). The remaining emissions gap could be explained by other factors. These include differences in energy mix and resource efficiency, as well as the aforementioned caveats to country-level comparisons (Section 3).

EXHIBIT 4

The effect of population differences is largely counterbalanced by wealth differences between the UK and India



1 Adjusts the UK emissions for differences in population between the UK and India.
2 Adjusts the UK emissions for differences in GDP per capita between the UK and India.

SOURCE: Climate Tracker; Team analysis

- **Country-level emissions can be compared more holistically by using a range of indicators.** This allows for multiple perspectives as compared to using a single indicator, such as absolute CO_2 emissions. For example, despite having the highest CO_2 emissions among countries with GDP above US$300 billion, China has relatively low CO_2 emissions per capita and CO_2 emissions per GDP (Exhibit 5). Full tables are provided in the Appendix to illustrate this.

  Similarly, based on data from the International Energy Agency, Singapore ranks 27th out of 142 countries for per capita emissions, but 126th in terms of CO_2 emissions per dollar GDP.[22] Each indicator thus provides a different lens for a more holistic comparison between countries. A potentially useful indicator to consider is the amount of CO_2 emitted

[22] CO_2 Emissions from Fuel Combustion - 2015 Highlights by OECD/International Energy Agency

per dollar of GDP per capita. This provides possible insight into how ‘carbon-intensive’ countries are in generating economic value-add per person.

EXHIBIT 5

Example of rank differences when using a range of indicators

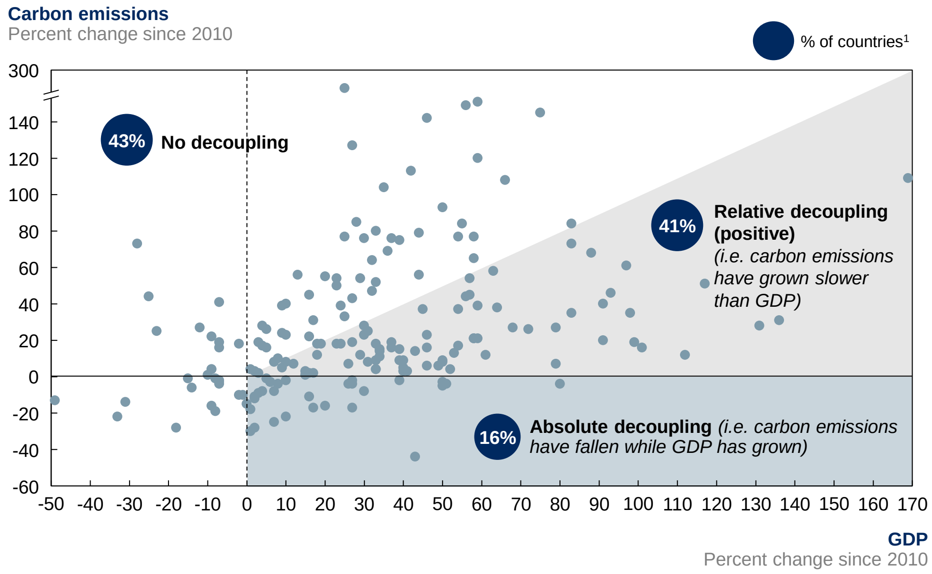
Indicator	CO_2 emissions	CO_2 emissions per capita	CO_2 emissions per GDP	CO_2 emissions / GDP per capita
Description	Absolute carbon emissions	Carbon intensity per person	Carbon intensity per unit of economic output	Carbon intensity of economic output per person
China’s rank[1]	1st	21st	7th	2nd

[1] Ranking is based on countries with GDP above US$300billion and is ordered from highest to lowest (i.e. 1st implies the country has the highest value of that indicator among the sample countries). The full tables are provided in the Appendix.

- **Decoupling GDP from carbon emissions is possible.** Emissions (adjusted for income) appear to decrease as countries become wealthier. This is known as ‘relative decoupling’ – carbon emissions continue to grow but at a slower rate than GDP. ‘Absolute decoupling’, where total emissions fall as GDP increases, has also been observed, albeit in fewer countries (Exhibit 6). Decoupling takes place mainly due to structural changes in the economy, improvements in energy efficiency and shifts in energy mix towards renewable sources. The next section explains these factors further.

EXHIBIT 6

While 41% percent of countries have seen a relative decoupling in carbon emissions to GDP since 2010, few have seen an absolute decoupling



1. Considered 170 countries where data is available.
SOURCE: Carbon Atlas; Team analysis

5. Urgent decoupling of economic growth from carbon emissions is needed to limit temperature increases

Based on the current emissions trajectory, global efforts are needed to accelerate decoupling in both developed and emerging economies. Research suggests that it is possible for emerging economies to leapfrog into a low-carbon future without going through a high-emissions development phase. The International Monetary Fund (IMF) illustrates how some countries, including emerging economies like Brazil, China, India, and Indonesia, are starting to show signs of relative decoupling. Germany, the United Kingdom, and France have also achieved absolute decoupling, with emissions declining as output grows.[21]

Decoupling of GDP and carbon emissions can be explained by several factors. For example, absolute decoupling in Germany, the United Kingdom, and France have been driven by decarbonising policies, as well as structural transformation towards service-driven economies. These countries have seen the largest improvement in energy efficiency policies, as tracked by the Efficiency Policy Progress Index (EPPI).[23]

Progress in the United States has been driven mainly by changes in energy mix – a shift from coal to natural gas for electricity generation. The share of coal power plants has fallen over the last 30 years, from 57 percent in 1988 to 30 percent in 2017, while gas-fired generation has increased from 10 percent to 32 percent over the same period.[24]

Large emerging economies have yet to achieve absolute decoupling, but China is showing signs of progress over the past decades and at the provincial level. [21]

However, given the caveats for country-level comparisons (Section 3), these results need to be analysed more closely. Some research suggests that apparent decoupling in developed countries has, to some degree, been driven by displacement of emissions through foreign trade (i.e. embedded emissions).[25] For example, in the United Kingdom, while emissions from domestic production have declined, emissions embedded in imported goods have increased

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[23] Developed by the International Energy Agency (IEA), the Efficiency Policy Progress Index (EPPI) is the main indicator of global progress on mandatory energy efficiency policy. For more information, please refer to IEA (2018), *Energy Efficiency 2018.* Available at: https://webstore.iea.org/download/direct/2369?fileName=Market_Report_Series_Energy_Efficiency_2018.pdf

[24] Reuters (2018), "U.S. power producers' coal consumption falls to 35-year low: Kemp". Available at: https://www.reuters.com/article/us-usa-coal-kemp/u-s-power-producers-coal-consumption-falls-to-35-year-low-kemp-idUSKCN1M61ZX

[25] Magnus Jiborn, Astrid Kandera, Viktoras Kulionis, Hana Nielsen, Daniel Moran (March 2018), "Decoupling or delusion? Measuring emissions displacement in foreign trade", Global Environmental Change, Volume 49. Available at: https://www.sciencedirect.com/science/article/pii/S095937801630454X

and currently represent more than half of the total carbon footprint associated with domestic consumption.[26]

While consumption-based accounting (which adjusts for emissions linked to trade) might weaken the evidence for relative and absolute decoupling, an IMF working paper explains that decoupling is still observed in some economies. To quote the paper, "taking account of consumption-based emissions weakens the case for progress but does not overturn it. Encouragingly, we find suggestive evidence that trend elasticities can be lowered through policy efforts on the part of countries."[21]

6. Collective action is required from governments, businesses and consumers to achieve a low-carbon future

Some developed countries have shown that economic prosperity and carbon efficiency can go hand in hand. Achieving the Paris Agreement targets, however, will require even more countries to decouple economic growth from carbon emissions. Collective action is thus needed from governments, businesses and consumers to achieve this.

Governments

There is a large body of literature examining policy options available for governments to support the shift to a low-carbon economy. These range from decarbonising the country's energy mix through levers such as feed-in tariffs and carbon pricing, to implementing energy efficiency standards on products.[21]

Governments could start by driving resource efficiency in carbon-intensive industries. For example, there are large resource efficiency differences between countries in various sectors (Exhibit 7). For example, building energy efficiency can vary by as much as 90 percent across countries.

Governments could thus incorporate lessons and best practices from countries which demonstrate better performance in resource efficiency. Several governments have introduced efficiency standards in specific sectors to enforce higher energy efficiency. The Top Runner programme in Japan mandates manufacturers to improve the energy efficiency of their

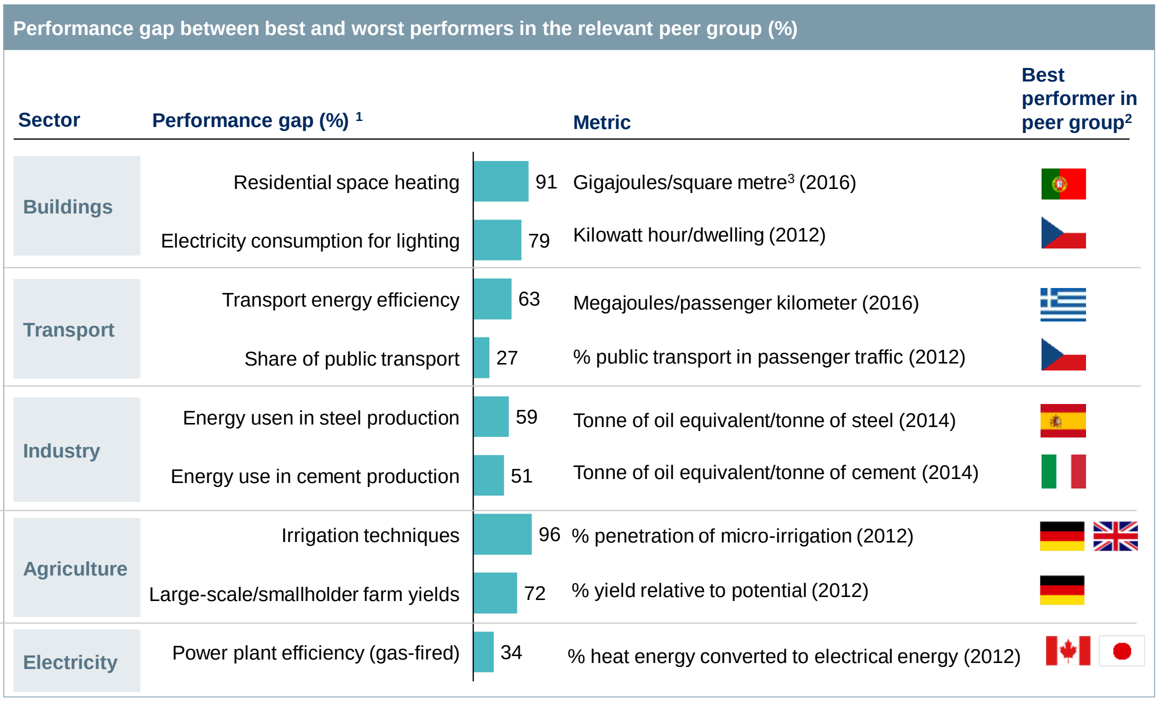
[26] The Guardian (2013), "UK's carbon footprint rises 3%". Available at https://www.theguardian.com/environment/2016/aug/02/uks-carbon-footprint-rises-3

products to a benchmark within a specified period (with a benchmark-resetting mechanism for the next period).[27]

Singapore has also taken steps to improve energy efficiency. The government developed the Green Mark Standard which applies to all buildings with centralised cooling systems and Gross Floor Area greater than 5,000m^2. These buildings are required to conduct periodic energy efficiency audits throughout the lifespan of the cooling systems.[28] District cooling approaches have also been adopted to achieve significant gains in energy efficiency. District cooling is the centralised production of chilled water piped to buildings located close to one another within a district for air conditioning. The district cooling network in Marina Bay Sands is one of the largest in the world, and the energy saved could power 24,000 three-room Housing and Development Board (HDB) units.[29]

EXHIBIT 7

There are large resource efficiency differences between countries



1. Performance gap is the percentage difference between best and poorest performers in the relevant peer group. In cases where the metric itself is a percent, we take the difference; otherwise, we take the percent change versus the top performer.
2. Peer group varies between metrics based on the availability of data and comparability.
3. Corrected for temperature.

SOURCE: IEA; FAO; ODYSSEE; McKinsey; AlphaBeta analysis

[27] McKinsey Global Institute (2011), *Resource Revolution: Meeting the world's energy, materials, food, and water needs*. Accessed at: https://www.mckinsey.com/business-functions/sustainability/our-insights/resource-revolution
[28] Building and Construction Authority (2017), "Existing Building Legislation". Available at: https://www.bca.gov.sg/EnvSusLegislation/Existing_Building_Legislation.html
[29] Liyana Othman (2016), "World's biggest underground district cooling network now at Marina Bay", TodayOnline. Accessed at: https://www.todayonline.com/singapore/plant-underground-district-cooling-network-marina-bay-commissioned

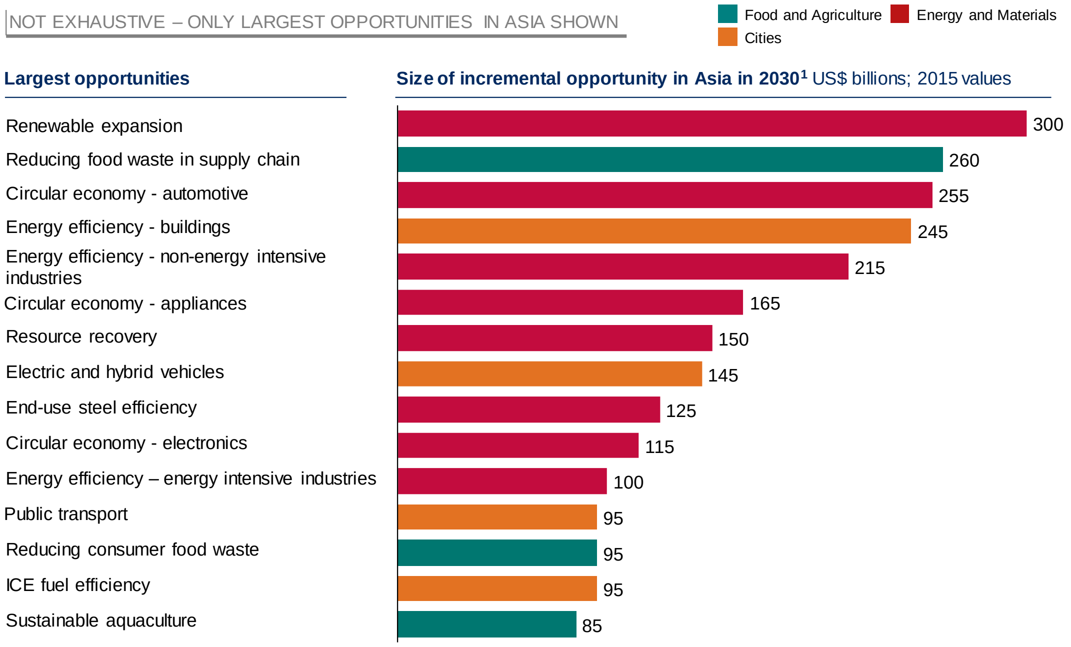
Businesses

Businesses also stand to reap commercial opportunities from improved carbon productivity. The Business & Sustainable Development Commission (BSDC) has identified US$5 trillion in business opportunities associated with implementing the Sustainable Development Goals (SDGs) in Asia in 2030.[30] Of that figure, over 60 percent, equivalent to around US$3.1 trillion of opportunities, could have a significant impact in reducing carbon emissions.

Exhibit 8 provides an overview of some of the largest business opportunities associated with reducing carbon emissions in Asia. For example, emissions embedded in vehicles and electronic equipment can be reduced by 43% and 45% respectively through recycling, and even more through product reuse and lifetime extension.

EXHIBIT 8

There are large business opportunities in Asia associated with reducing carbon emissions



1. Based on estimated savings or projected market sizings in each area. Only the high case opportunity is shown here. Rounded to nearest US$5 billion.

SOURCE: Literature search; AlphaBeta analysis

Up till 2008, approximately 2 million vehicles were disposed in China every year. Over 20 million vehicles a year is projected to be disposed in China by 2020.[31] End-of-life vehicles (ELVs) could be exported as second-hand or be sent to scrap metal companies for reusing and recycling of parts. Typically, the failure of a small number of 'weakest-link' components is responsible for

[30] Business & Sustainable Development Commission (2017), *Better Business Better World Asia*. Accessed at: http://report.businesscommission.org/reports/better-business-better-world-asia
[31] Peter Dauvergne (2008). The Shadows of Consumption: Consequences for the Global Environment.

ELVs. It is thus possible to extend vehicular life spans by increasing rates of refurbishment and remanufacturing of these components, thereby raising the vehicle's residual value.

Another innovative circular model is Michelin's scheme for billing customers based on 'miles travelled', instead of selling the physical product. This transforms goods into services, significantly lowering carbon emissions.[32]

There is also a range of new tools available, including the carbon productivity tool, which can help businesses identify opportunities to enhance carbon productivity.[33]

Consumers

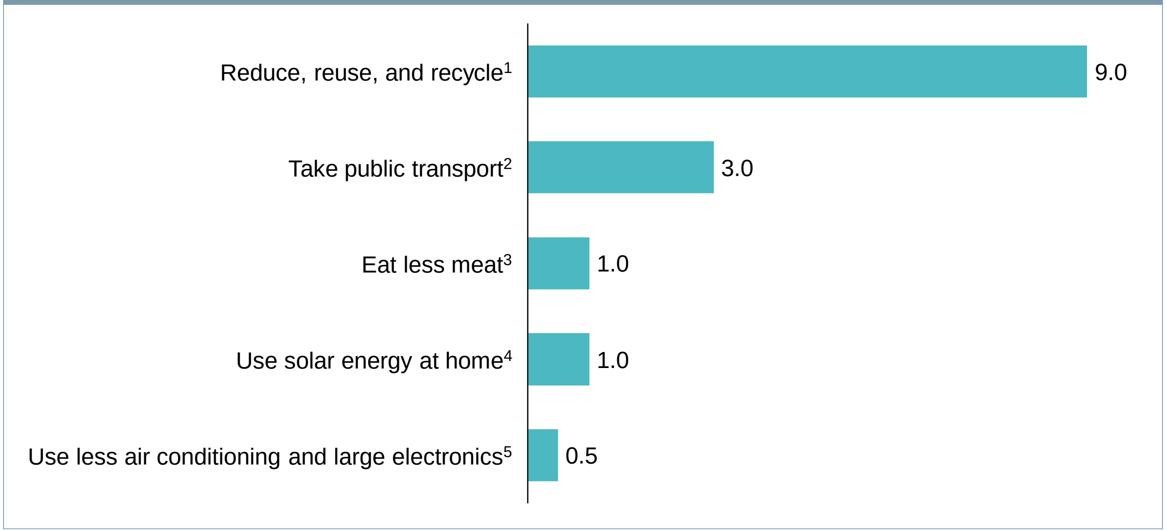
Beyond regulations and business initiatives to improve energy efficiency and implement shifts in energy mix, consumption patterns also need to change. Consumers can take action to lower their carbon footprints in the following ways (Exhibit 9). The list below is not meant to be exhaustive or definitive but could be a useful starting point.

EXHIBIT 9

There are a range of opportunities that each person can take advantage of to reduce their carbon footprint

SINGAPORE EXAMPLE

Opportunities to reduce per capita carbon emissions (tonnes of CO_2 per year)



1. Difference between shopping often, preferring international goods and high levels of packaging, and no recycling versus having a minimalist lifestyle, reusing, repairing, and recycling.
2. Difference between driving alone versus using public transport.
3. Difference between eating all types of meat daily versus eating vegetables or seafood only.
4. Difference between living in a normal executive HDB flat or condo versus living in a solar-powered home.
5. Difference between using air conditioner and large electronic devices often versus not using them often.

SOURCE: What is my carbon footprint; AlphaBeta analysis

[32] Business & Sustainable Development Commission, Temasek and AlphaBeta (2017), *Better Business Better World Asia*. Available at: http://report.businesscommission.org/reports/better-business-better-world-asia

[33] For more information, see: http://carbonproductivity.com/

- **Reduce, reuse, and recycle**. By adopting the 3 'R's, consumers could reduce emissions per individual by up to nine tonnes of CO_2 emissions per year. Recycling aluminium, plastics, and paper can help achieve carbon footprint savings of at least 60 percent compared to virgin resources.[34] Reducing food waste is also effective in curbing carbon emissions. In Singapore, food waste accounts for about 10 percent of the total waste generated, but only 16 percent of food waste is recycled.[35] Other examples include reusing clothes and shopping bags, using less packaging, and switching to reusable bottles and containers.

- **Take public transport**. Vehicles are the second-largest contributor to emissions in Singapore, after industry.[36] Taking public transportation instead of driving can help lower one's carbon footprint linked to transportation by 85 percent, or up to three tonnes of CO_2 emissions reduction per year.

- **Eat less meat.** If the global population shifts to a diet recommended by the World Health Organisation (WHO) of only 160g of meat per day, up to 15 $GtCO_2e$[37] can potentially be saved per year by 2050 – equivalent to a third of all global CO_2 emissions in 2011.[38] Individuals can cut their food-related CO_2 emissions by one tonne (Exhibit 9) or about 40 percent per year, by shifting from a meat-based diet to a seafood or plant-based one.[39]

- **Use solar energy at home.** Solar energy not only reduces carbon emissions but can also be cost-effective. For example, a typical household in the United States can save up to US$32,000 of electricity costs over the lifespan of a solar system.[40] Consumers in Singapore may also enjoy cost savings from solar energy as the installed capacity increases and through the Open Electricity Market initiative with retailers offering discounts. Singapore has also set a target of installing solar panels on 5,500 HDB blocks by 2020.[41]

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[34] Shrink that footprint, "Shrink your product footprint". Available at: http://shrinkthatfootprint.com/shrink-your-product-footprint
[35] National Environmental Agency, "Food Waste Management". Available at: https://www.nea.gov.sg/our-services/waste-management/3r-programmes-and-resources/food-waste-management
[36] Today (2017), "Higher emission standards for petrol vehicles, motorbikes from next April". Available at: https://www.todayonline.com/singapore/tighter-emission-standards-petrol-vehicles-april-2018
[37] Gigatonnes of equivalent carbon dioxide
[38] The City Fix (2015). Available at: https://thecityfix.com/blog/global-calculator-choosing-your-2-degree-pathway-cop21-erin-cooper-ryan-winstead-alex-rogala/
[39] What is my carbon footprint (2016). Available at: https://whatismycarbonfootprint.com/#about
[40] Energy Sage (2019), "Avoid utility inflation". Available at: https://www.energysage.com/solar/why-go-solar/reduce-energy-costs/
[41] The Straits Times (2017), "No big cost savings yet, but solar panels vital for energy goals". Available at: https://www.straitstimes.com/singapore/no-big-cost-savings-yet-but-solar-panels-vital-for-energy-goals

- **Minimise use of electronic devices**. Air conditioning can account for up to 50 percent of Singapore's electricity demand during peak usage periods.[42] Keeping the set air conditioning temperature at 25°C can reduce energy consumption of the building by 10 percent.[43] Unplugging mobile phone chargers when not in use is another way to reduce one's carbon footprint, as up to 95 percent of energy is wasted when the charger is plugged in.[44]

7. Conclusion

There are many pathways to a low-carbon future. While there are challenges in comparing carbon emissions across countries, the evidence presented in this paper suggests that increasing economic prosperity need not necessarily be at the expense of increasing emissions. By adopting a multi-stakeholder approach and cross-referencing different indicators to track progress, more countries – regardless of developmental stages – will be able to achieve relative and absolute decoupling.

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[42] IEA (2018) The Future of Cooling: Opportunities for energy-efficient air conditioning Available at: https://webstore.iea.org/download/direct/1036?fileName=The_Future_of_Cooling.pdf
[43] The Straits Times (2016), "Cool idea for cities to cut CO_2 emissions". Available at: https://www.straitstimes.com/singapore/cool-idea-for-cities-to-cut-co2-emissions
[44] WHO (2008), *Reducing carbon footprint can be good for your health".* Available at: https://www.who.int/globalchange/publications/factsheets/Kit2008_annex1_2.pdf?ua=1

Appendix: Country emissions can be compared based on various indicators

Table 1. Countries with GDP above US$300 billion ranked by CO_2 emissions[1]

Rank	Country	CO_2 emissions[2] ($MtCO_2$)	Nominal GDP[2] (US$B)	Population[2] (M)	CO_2 emissions (tonnes) per capita	CO_2 emissions ($MtCO_2$) / GDP (US$B)	CO_2 emissions ($MtCO_2$) / GDP (US$K) per capita
1	China	9,839	12,238	1386.40	7.10	0.80	1114.62
2	USA	5,270	19,391	325.72	16.18	0.27	88.52
3	India	2,467	2,597	1339.18	1.84	0.95	1271.79
4	Russia	1,693	1,578	144.50	11.72	1.07	155.05
5	Japan	1,205	4,872	126.79	9.50	0.25	31.36
6	Germany	799	3,677	82.70	9.67	0.22	17.98
7	Iran	672	440	81.16	8.28	1.53	124.15
8	Saudi Arabia	635	684	32.94	19.28	0.93	30.59
9	South Korea	616	1,531	51.47	11.97	0.40	20.71
10	Canada	573	1,653	36.71	15.60	0.35	12.72
11	Mexico	490	1,150	129.16	3.80	0.43	55.07
12	Indonesia	487	1,016	263.99	1.84	0.48	126.55
13	Brazil	476	2,056	209.29	2.27	0.23	48.47
14	South Africa	456	349	56.72	8.05	1.31	74.07
15	Turkey	448	851	80.75	5.55	0.53	42.49
16	Australia	413	1,323	24.60	16.79	0.31	7.68
17	United Kingdom	385	2,622	66.02	5.83	0.15	9.69
18	France	356	2,583	67.12	5.31	0.14	9.26
19	Italy	355	1,935	60.55	5.87	0.18	11.12
20	Thailand	331	455	69.04	4.79	0.73	50.17
21	Poland	327	525	37.98	8.60	0.62	23.65
22	Spain	281	1,311	46.57	6.04	0.21	9.99
23	Malaysia	255	315	31.62	8.05	0.81	25.60
24	UAE	232	383	9.40	24.66	0.61	5.69
25	Argentina	204	638	44.27	4.62	0.32	14.19
26	Pakistan	199	305	197.02	1.01	0.65	128.44
27	Netherlands	164	826	17.13	9.58	0.20	3.40
28	Philippines	128	314	104.92	1.22	0.41	42.69
29	Nigeria	107	376	190.89	0.56	0.29	54.51
30	Belgium	100	493	11.37	8.80	0.20	2.31
31	Colombia	81	309	49.07	1.66	0.26	12.89
32	Austria	70	417	8.81	7.94	0.17	1.48
33	Israel	67	351	8.71	7.64	0.19	1.65
34	Singapore	65	324	5.61	11.54	0.20	1.12
35	Norway	45	399	5.28	8.48	0.11	0.59
36	Hong Kong	43	341	7.39	5.82	0.13	0.93
37	Sweden	42	538	10.07	4.12	0.08	0.78
38	Switzerland	40	679	8.47	4.73	0.06	0.50
39	Ireland	40	334	4.81	8.26	0.12	0.57
40	Denmark	35	325	6	5.99	0.11	0.61

[1] Sources: Global Carbon Atlas; World Bank; OECD CO_2 emissions in Million tonnes

[2] Based on 2017 data

Table 2. Countries with GDP above US\$300 billion ranked by CO_2 emissions per capita[1]

Rank	Country	CO_2 emissions[2] ($MtCO_2$)	Nominal GDP[2] (US\$B)	Population[2] (M)	CO_2 emissions (tonnes) per capita	CO_2 emissions ($MtCO_2$) / GDP (US\$B)	CO_2 emissions ($MtCO_2$) / GDP (US\$K) per capita
1	UAE	232	383	9.40	24.66	0.61	5.69
2	Saudi Arabia	635	684	32.94	19.28	0.93	30.59
3	Australia	413	1,323	24.60	16.79	0.31	7.68
4	USA	5,270	19,391	325.72	16.18	0.27	88.52
5	Canada	573	1,653	36.71	15.60	0.35	12.72
6	South Korea	616	1,531	51.47	11.97	0.40	20.71
7	Russia	1,693	1,578	144.50	11.72	1.07	155.05
8	Singapore	65	324	5.61	11.54	0.20	1.12
9	Germany	799	3,677	82.70	9.67	0.22	17.98
10	Netherlands	164	826	17.13	9.58	0.20	3.40
11	Japan	1,205	4,872	126.79	9.50	0.25	31.36
12	Belgium	100	493	11.37	8.80	0.20	2.31
13	Poland	327	525	37.98	8.60	0.62	23.65
14	Norway	45	399	5.28	8.48	0.11	0.59
15	Iran	672	440	81.16	8.28	1.53	124.15
16	Ireland	40	334	4.81	8.26	0.12	0.57
17	Malaysia	255	315	31.62	8.05	0.81	25.60
18	South Africa	456	349	56.72	8.05	1.31	74.07
19	Austria	70	417	8.81	7.94	0.17	1.48
20	Israel	67	351	8.71	7.64	0.19	1.65
21	China	9,839	12,238	1386.40	7.10	0.80	1114.62
22	Spain	281	1,311	46.57	6.04	0.21	9.99
23	Denmark	35	325	5.77	5.99	0.11	0.61
24	Italy	355	1,935	60.55	5.87	0.18	11.12
25	United Kingdom	385	2,622	66.02	5.83	0.15	9.69
26	Hong Kong	43	341	7.39	5.82	0.13	0.93
27	Turkey	448	851	80.75	5.55	0.53	42.49
28	France	356	2,583	67.12	5.31	0.14	9.26
29	Thailand	331	455	69.04	4.79	0.73	50.17
30	Switzerland	40	679	8.47	4.73	0.06	0.50
31	Argentina	204	638	44.27	4.62	0.32	14.19
32	Sweden	42	538	10.07	4.12	0.08	0.78
33	Mexico	490	1,150	129.16	3.80	0.43	55.07
34	Brazil	476	2,056	209.29	2.27	0.23	48.47
35	Indonesia	487	1,016	263.99	1.84	0.48	126.55
36	India	2,467	2,597	1339.18	1.84	0.95	1271.79
37	Colombia	81	309	49.07	1.66	0.26	12.89
38	Philippines	128	314	104.92	1.22	0.41	42.69
39	Pakistan	199	305	197.02	1.01	0.65	128.44
40	Nigeria	107	376	190.89	0.56	0.29	54.51

[1] Sources: Global Carbon Atlas; World Bank; OECD; CO_2 emissions in Million tonnes

[2] Based on 2017 data

Table 3. Countries with GDP above US$300 billion ranked by CO_2 emissions per GDP[1]

Rank	Country	CO_2 emissions[2] ($MtCO_2$)	Nominal GDP[2] (US$B)	Population[2] (M)	CO_2 emissions (tonnes) per capita	CO_2 emissions ($MtCO_2$) / GDP (US$B)	CO_2 emissions ($MtCO_2$) / GDP (US$K) per capita
1	Iran	672	440	81.16	8.28	1.53	124.15
2	South Africa	456	349	56.72	8.05	1.31	74.07
3	Russia	1,693	1,578	144.50	11.72	1.07	155.05
4	India	2,467	2,597	1339.18	1.84	0.95	1271.79
5	Saudi Arabia	635	684	32.94	19.28	0.93	30.59
6	Malaysia	255	315	31.62	8.05	0.81	25.60
7	China	9,839	12,238	1386.40	7.10	0.80	1114.62
8	Thailand	331	455	69.04	4.79	0.73	50.17
9	Pakistan	199	305	197.02	1.01	0.65	128.44
10	Poland	327	525	37.98	8.60	0.62	23.65
11	UAE	232	383	9.40	24.66	0.61	5.69
12	Turkey	448	851	80.75	5.55	0.53	42.49
13	Indonesia	487	1,016	263.99	1.84	0.48	126.55
14	Mexico	490	1,150	129.16	3.80	0.43	55.07
15	Philippines	128	314	104.92	1.22	0.41	42.69
16	South Korea	616	1,531	51.47	11.97	0.40	20.71
17	Canada	573	1,653	36.71	15.60	0.35	12.72
18	Argentina	204	638	44.27	4.62	0.32	14.19
19	Australia	413	1,323	24.60	16.79	0.31	7.68
20	Nigeria	107	376	190.89	0.56	0.29	54.51
21	USA	5,270	19,391	325.72	16.18	0.27	88.52
22	Colombia	81	309	49.07	1.66	0.26	12.89
23	Japan	1,205	4,872	126.79	9.50	0.25	31.36
24	Brazil	476	2,056	209.29	2.27	0.23	48.47
25	Germany	799	3,677	82.70	9.67	0.22	17.98
26	Spain	281	1,311	46.57	6.04	0.21	9.99
27	Netherlands	164	826	17.13	9.58	0.20	3.40
28	Singapore	65	324	5.61	11.54	0.20	1.12
29	Belgium	100	493	11.37	8.80	0.20	2.31
30	Israel	67	351	8.71	7.64	0.19	1.65
31	Italy	355	1,935	60.55	5.87	0.18	11.12
32	Austria	70	417	8.81	7.94	0.17	1.48
33	United Kingdom	385	2,622	66.02	5.83	0.15	9.69
34	France	356	2,583	67.12	5.31	0.14	9.26
35	Hong Kong	43	341	7.39	5.82	0.13	0.93
36	Ireland	40	334	4.81	8.26	0.12	0.57
37	Denmark	35	325	5.77	5.99	0.11	0.61
38	Norway	45	399	5.28	8.48	0.11	0.59
39	Sweden	42	538	10.07	4.12	0.08	0.78
40	Switzerland	40	679	8.47	4.73	0.06	0.50

[1] Sources: Global Carbon Atlas; World Bank; OECD; CO_2 emissions in Million tonnes

[2] Based on 2017 data

Table 4. Countries with GDP above US$300 billion ranked by CO_2 emissions per GDP per capita[1]

Rank	Country	CO_2 emissions[2] ($MtCO_2$)	Nominal GDP[2] (US$B)	Population[2] (M)	CO_2 emissions (tonnes) per capita	CO_2 emissions ($MtCO_2$) / GDP (US$B)	CO_2 emissions ($MtCO_2$) / GDP (US$K) per capita
1	India	2,467	2,597	1,339.18	1.84	0.95	1271.79
2	China	9,839	12,238	1,386.40	7.10	0.80	1114.62
3	Russia	1,693	1,578	144.50	11.72	1.07	155.05
4	Pakistan	199	305	197.02	1.01	0.65	128.44
5	Indonesia	487	1,016	263.99	1.84	0.48	126.55
6	Iran	672	440	81.16	8.28	1.53	124.15
7	USA	5,270	19,391	325.72	16.18	0.27	88.52
8	South Africa	456	349	56.72	8.05	1.31	74.07
9	Mexico	490	1,150	129.16	3.80	0.43	55.07
10	Nigeria	107	376	190.89	0.56	0.29	54.51
11	Thailand	331	455	69.04	4.79	0.73	50.17
12	Brazil	476	2,056	209.29	2.27	0.23	48.47
13	Philippines	128	314	104.92	1.22	0.41	42.69
14	Turkey	448	851	80.75	5.55	0.53	42.49
15	Japan	1,205	4,872	126.79	9.50	0.25	31.36
16	Saudi Arabia	635	684	32.94	19.28	0.93	30.59
17	Malaysia	255	315	31.62	8.05	0.81	25.60
18	Poland	327	525	37.98	8.60	0.62	23.65
19	South Korea	616	1,531	51.47	11.97	0.40	20.71
20	Germany	799	3,677	82.70	9.67	0.22	17.98
21	Argentina	204	638	44.27	4.62	0.32	14.19
22	Colombia	81	309	49.07	1.66	0.26	12.89
23	Canada	573	1,653	36.71	15.60	0.35	12.72
24	Italy	355	1,935	60.55	5.87	0.18	11.12
25	Spain	281	1,311	46.57	6.04	0.21	9.99
26	United Kingdom	385	2,622	66.02	5.83	0.15	9.69
27	France	356	2,583	67.12	5.31	0.14	9.26
28	Australia	413	1,323	24.60	16.79	0.31	7.68
29	UAE	232	383	9.40	24.66	0.61	5.69
30	Netherlands	164	826	17.13	9.58	0.20	3.40
31	Belgium	100	493	11.37	8.80	0.20	2.31
32	Israel	67	351	8.71	7.64	0.19	1.65
33	Austria	70	417	8.81	7.94	0.17	1.48
34	Singapore	65	324	5.61	11.54	0.20	1.12
35	Hong Kong	43	341	7.39	5.82	0.13	0.93
36	Sweden	42	538	10.07	4.12	0.08	0.78
37	Denmark	35	325	5.77	5.99	0.11	0.61
38	Norway	45	399	5.28	8.48	0.11	0.59
39	Ireland	40	334	4.81	8.26	0.12	0.57
40	Switzerland	40	679	8.47	4.73	0.06	0.50

[1] Sources: Global Carbon Atlas; World Bank; OECD; CO_2 emissions in Million tonnes

[2] Based on 2017 data