Carbon Dioxide Emissions by the Four Largest World Emitters: Past Performance and Future Scenarios for China, U.S.A., Europe and India

Sylvain Cail [a] *and* **Patrick Criqui** [a,b]
[a] *Enerdata,* [b] *Université Grenoble Alpes-CNRS*

Sylvain Cail (sylvain.cail@enerdata.net) *is a senior expert in the modelling and analysis of energy markets worldwide and at country level. His fields of expertise comprise the modelling of interactions between energy and climate policies, and their potential effects on energy demand, supply and the development of energy prices. In particular, he has an extensive knowledge of the use and development of energy models like POLES-Enerdata to build and assess long-term energy and climate scenarios. At Enerdata, Sylvain manages the Global Energy Forecasting department, helping public and private clients from the energy and industry sectors.*

Patrick Criqui (patrick.criqui@univ-grenoble-alpes.fr) *is a senior researcher emeritus at CNRS, working on the economics of energy transition and climate policies in the Grenoble Applied Economics Laboratory. His main research area has been the development of a world long term energy model, POLES, used by the European Commission and different institutions in Europe to analyze the economics of climate policies. He has been a lead author in IPCC's Working Group 3. Member of the Economic Council for Sustainable Development by the French Ministry of Ecology since 2008, he currently works on deep decarbonization scenarios. He is a research associate at IDDRI and Enerdata.*

Introduction

The purpose of this paper is to clarify the magnitude of the climate challenge we face globally and the role that the four largest greenhouse gas emitters – China, the U.S.A., the European Union[1] and India – could potentially play, if they decided on a "deep collaboration". As stated in IPCC's 1.5°C report[2], the challenge is indeed to bring global emissions down to a level where they could be compensated for by anthropogenic carbon capture from the atmosphere.

In this paper, we focus on the abatement of CO_2 emissions as they represent two thirds of total GHG emissions[3]. By doing so, we recognise that confining our data to CO_2 ignores other important gases (methane, nitrous oxides, fluorinated gases) and their emission dynamics. But introducing the other greenhouse gases would make our analysis more fragile, by lack of consistent and reliable time-series. In Annex II we discuss this incompleteness.

The role that a deep climate collaboration could play in aiming at net zero emissions by mid-century (or shortly after) is twofold: first, as they today represent nearly 60 % of total CO_2 emissions, the implementation of carbon neutrality policies in their own jurisdiction would have a major global impact; second the implementation of these policies in the compact will have a significant leverage effect on the other countries, both by the demonstration effect and by the learning effect for low or zero carbon technologies that would benefit every country.

The paper proceeds along three stages. In section 2. "Where we stand, a global view", we recall the dynamics of atmospheric concentrations for two major GHGs, CO_2 and methane. In section 3. "Looking back", we analyse in more detail the trends and bifurcations in the emissions for each of the four constituencies we are considering. Finally, in section 4. "Where we need to go", we analyse for the same constituencies representative scenarios that will allow us to contrast current developments with more constrained trajectories meeting the Paris commitments and, further on, net zero ambitions.

1 In this paper, we define and consider Europe as the European Union plus the United Kingdom (EU27+1 in the Figures). This is by convenience, for reasons of time-series continuity and while taking into account the fact that UK's net zero emissions policy of 2020 keeps in line with the European Union's perspective.

2 www.ipcc.ch/sr15/chapter/spm/

3 www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

In presenting these data and scenarios, there is no implication of judgment or blame, on who is responsible and who should do what. The purpose is to establish a clear vision of the problem and perhaps engender fruitful discussions about how to make progress at scale.

Where we stand, a global view

Climate change is to a large extent the result of the increase in the concentration of greenhouse gasses in the atmosphere, due to human activity. The continuous stock building of CO_2 and methane in the atmosphere are shown below: between 1984 and 2019, CO_2 and methane concentrations have increased by respectively 19% and 13% (Figure 1).

The concentration of anthropogenic CO_2 in the atmosphere is the result of a process that goes back to the industrial revolution, from the beginning of the 19th century. At this moment of history, fossil fuels – initially coal – start to be used as a source of energy. Their rapidly growing importance and supremacy will be confirmed all along the 20th century and early 21st century (Smil, 2019 and Grubler, 2012). However, the take-off in world emissions from fossil energy really takes place after WWII. As shown in Figure 2, the increase is initially moderate and total CO_2 emissions amount to only 5 Gt CO_2 in 1945. They multiplied by a factor of more than 3.5 by 1979, year of the second oil shock, and then again by a factor of 1.9 by 2019.

This perspective reveals the fact that the causes of the build-up of the climate problem pertain to relatively recent economic history. The problem is that the accumulated GHG stock (especially CO_2) is here to stay… for long.

Looking back at the "big four"

Over the past sixty years, world total CO_2 emissions have grown in an almost linear way, which means that the growth rate progressively

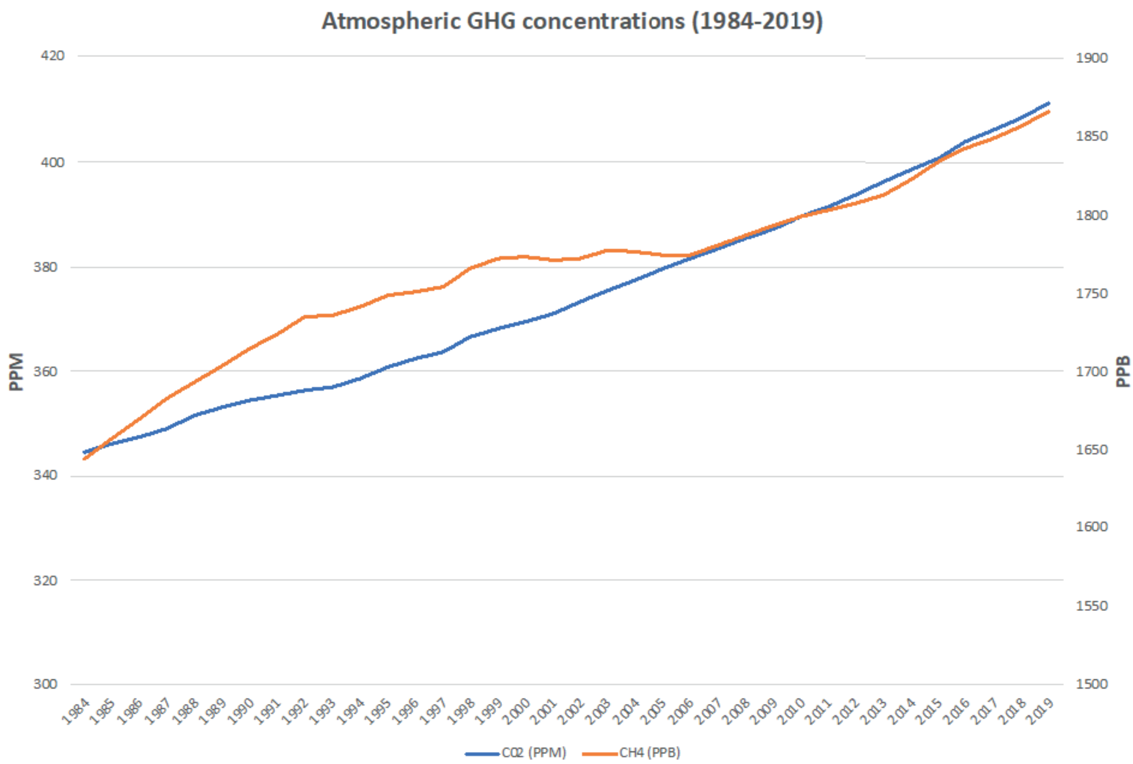

Figure 1. Trends in Atmospheric Concentrations of Carbon Dioxide (CO_2) and Methane (CH4)
Source: NOAA atmospheric GHG statistics (www.esrl.noaa.gov/gmd/ccgg/trends_ch4)

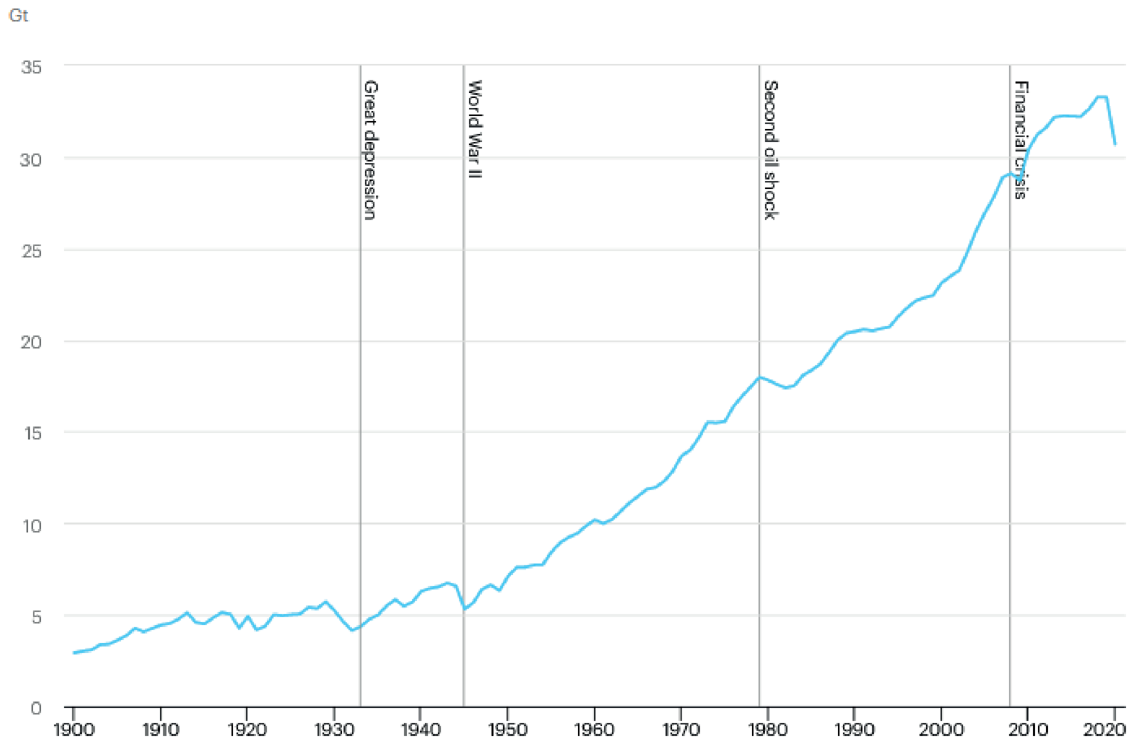

Figure 2. CO_2 emissions, 1900-2020
Source: IEA (www.iea.org/data-and-statistics/charts/global-energy-related-co2-emissions-1900-2020)

decelerates. But what is more striking, is the very uneven growth patterns of the four jurisdictions we are considering (Figure 3).

From 1960 to 1986, the emission trajectories in the U.S. and in Europe are almost identical, both in their level and dynamics. These paths diverge however after the second oil shock, when Europe's emissions start a decline, which accelerates after the financial crisis of 2008. By 2019, Europe's emissions are back to their 1965 level. U.S. emissions plateau only between 2000 and 2008 and begin their downside trajectory only after that date.

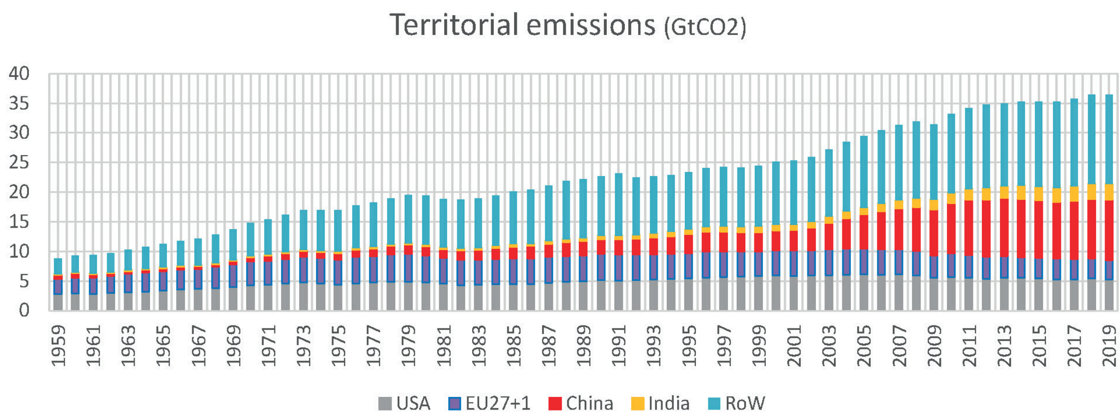

Figure 3. Total fossil CO_2 emissions, a sixty years' perspective (in billion tons of CO_2)
Source: Global Carbon Project, 2020 (www.globalcarbonproject.org)

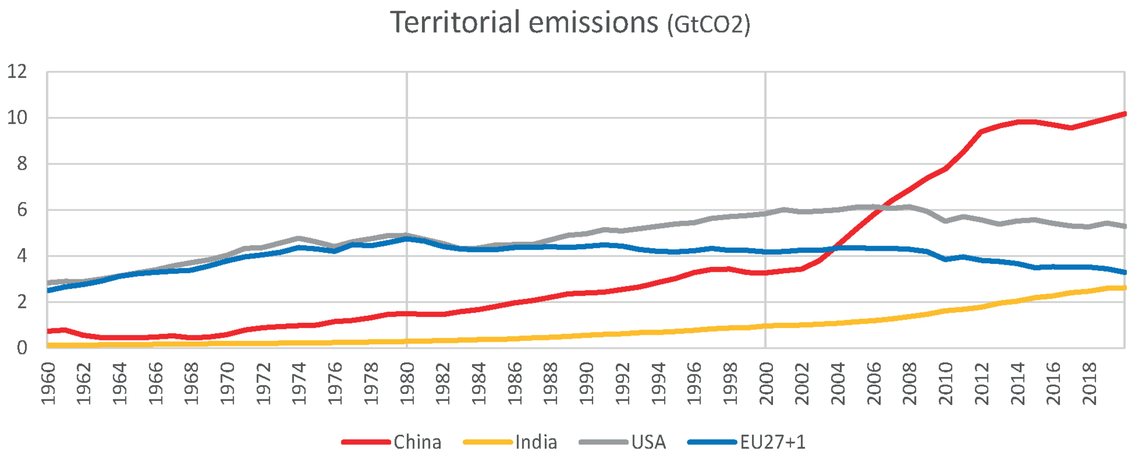

Figure 4. Total CO_2 emissions in the four regions (in billion tons of CO_2)
Source: Global Carbon Project, 2020

The story is different in China, where emissions increase at an annual average rate of 3-4% until 2001, the year of the accession of China to the World Trade Organization (WTO). After this date, economic growth accelerates as do total emissions: from 2001 to 2014, they increase from 3.5 to 9.8 Gt CO_2, i.e., an annual average growth rate of 8.4%. By 2004, China's total emissions overtake those of Europe's and in 2007 those of the U.S. India's emission trajectory shows a more regular profile, with an annual average growth rate of 5-6%. By the end of the period under review, India's total emissions approach those of Europe, while it only represented 4% of it in 1960. A new balance is in place.

This evolution is highlighted by the changes in the share of world emissions in the four jurisdictions from 1990 (the benchmark year for the Kyoto Protocol) to 2019 (Figure 5). Between these two dates the four regions have increased their joint share of the total, from 56% to 59%. This is due to the increase in China's share of world emissions, from 11 to 28%, and to a lesser extent to the increase of India's share, from 2 to 7%. Conversely, the U.S. and EU shares decrease over the same period, respectively from 23% to 15% and from 20% to 9%.

This new balance in world emissions reflects the major structural changes in the world economy during the past thirty years of globalization.

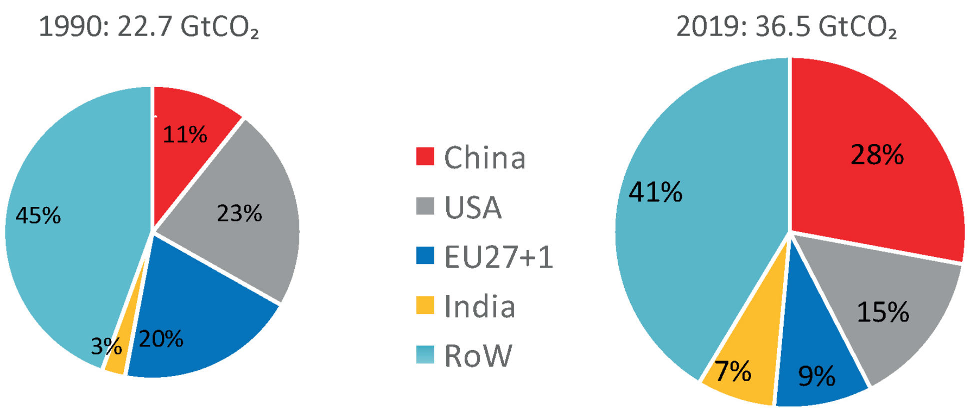

Figure 5. Share of total emissions for the different regions (in billions t CO_2)
Source: Global Carbon Project, 2020

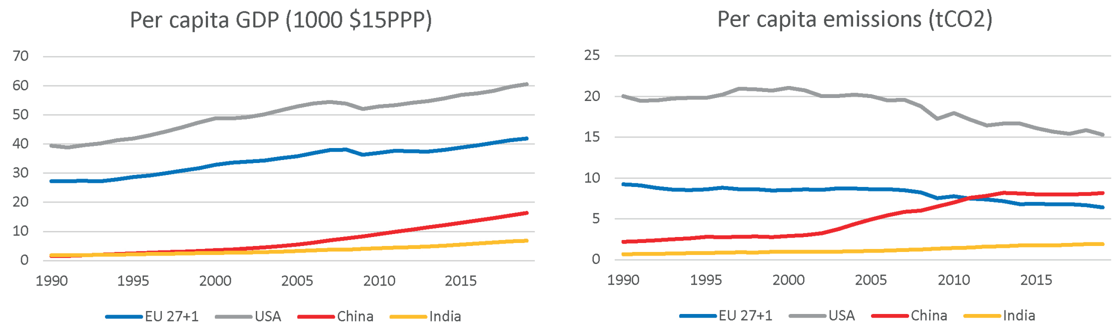

Figure 6a and 6b. Per capita GDP and per capita CO_2 emissions
Source: Enerdata, Global Energy and CO_2 Database, 2020

A per capita analysis

Per capita GDP (Figure 6a) increased in every region but at very different rates, according to the country's category, "mature" or "emerging": the U.S. and Europe both see their per capita GDP increase at an annual average growth rate of 1.4% during the 1990 to 2019 period. The equivalent rate is respectively of 8.4% and 4.5% for China and India. China's per capita GDP, which was 4% of the U.S. level in 1990 had risen to 27% thereof in 2019; for India the equivalent shares were 5% and 11%. Per capita emissions (Figure 6b) follow consistent – although not similar – patterns. While they decrease by 25 and 30 % respectively in the U.S. and the EU between 1990 and 2019, they significantly increase in China and India where they are respectively multiplied by a factor of 3.8% and 2.9%. By the end of the period, per capita emissions of China are higher than those of Europe.

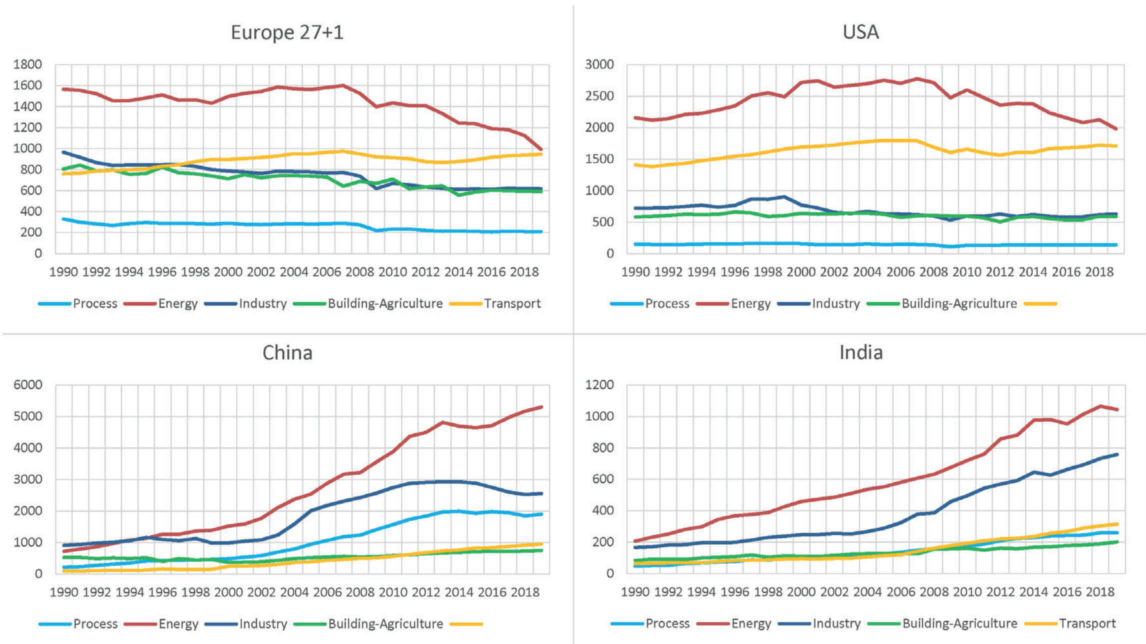

Figure 7. CO_2 emissions, by sector
Source: Enerdata, Global Energy and CO_2 Database, 2020
Note: "Process" stands for CO_2 emissions in the production process of materials (mostly steel and cement); "Energy" stands for emissions in the energy sector, mostly for electricity generation.

A sectoral analysis

The analysis of emissions by sector shows interesting similarities across the two pairs of jurisdictions: "mature" and "emerging". In Europe and in the U.S. the energy and transport sectors dominate the others, with similar profiles: the energy sector (mostly electricity generation) ranks first but has decreased strongly since the mid-2000s, while transport ranks second but is stable and even slightly increasing in recent years. The building and industry sectors are comparable, in level and trend, in both jurisdictions. However, the gap between transport and building is much larger in the U.S. than in Europe, which reflects the relative importance and carbon intensity of the transport activity in the U.S.

In the emerging countries, energy is also the leading emitting sector and has increased rapidly. But contrary to the economically mature jurisdictions, industry, and not transport, is the second highest source of emissions. In China as in India, transport and building are of similar relative importance, rising steadily, but well below industry.

Where we need to go

Together, China, the U.S.A., Europe, and India have been responsible for the emission of 22.6 $GtCO_2$ in 2019. The following section provides an overview of the possible evolution of CO_2 emissions (including industrial processes) in these jurisdictions. Scenarios are based on Enerdata's EnerFuture[4] prospective scenarios, which are performed with the POLES-Enerdata[5] model.

The scenarios presented here are EnerBlue and EnerGreen. EnerBlue is a scenario in which the Nationally Determined Contributions (NDCs) of the four jurisdictions are achieved in the next 10 years, and they continue on this reduction trajectory up to 2050. This scenario is compared to EnerGreen, a more ambitious 2°C-compatible scenario, which would require that a collective additional reduction in the order of 14.5Gt be achieved by 2050. In this scenario, the global carbon budget, in line with the IPCC scenarios (Rogelj et al., 2019), is apportioned to countries according to a "soft-landing" profile, based on capacity and responsibility criteria as developed by (Criqui et. al, 2014). These trajectories are only illustrative, as many other combinations of effort across the four jurisdictions could deliver the same aggregate outcome.

Taken together, CO_2 emissions of the four jurisdictions follow a slightly decreasing trend over the next 30 years in the NDC scenario (EnerBlue), reaching 22.3 $GtCO_2$ in 2030 and 20.7 $GtCO_2$ in 2050 (9% compared to 2019). At the global level, the EnerBlue scenario is likely to result in a temperature increase between 3 and 4°C by the end of the century, compared to pre-industrial levels. In the EnerGreen scenario, which is compatible with a 2°C temperature rise, CO_2 emissions of the four jurisdictions in aggregate are reduced by 72% over the period 2019-2050, which leaves approximately 6.2 $GtCO_2$ in 2050. The 14.5 $GtCO_2$ emissions gap observed in 2050 between the two scenarios reflects the significant effort required globally, and hence at the country level, to achieve the 2°C objective of the Paris Agreement.

This level of effort is illustrated for of each jurisdiction in the following four charts. While the EnerBlue scenario assumes a decreasing emission profile in developed economies (Europe, U.S.A.), the next 30 years look different in China (stable, then slightly decreasing) and India (steady increase of emissions). The additional emission reductions that would need to be delivered to achieve a 2°C future are significant in all jurisdictions, ranging between 61% (India) and 74% (U.S.A.) in terms of 2050 emissions gap. The total 14.5 $GtCO_2$ emission gap discussed above is in the hands of all four countries, whereby China, given its very high current level of CO_2 emissions, has a potential to reduce for half of it.

4 www.enerdata.net/research/forecast-enerfuture.html

5 POLES-Enerdata is the version of the POLES model run, developed and maintained by Enerdata. The POLES model has been initially developed by IEPE (Institute for Economics and Energy Policy), now GAEL lab (Grenoble Applied Economics Lab). www.enerdata.net/solutions/poles-model.html

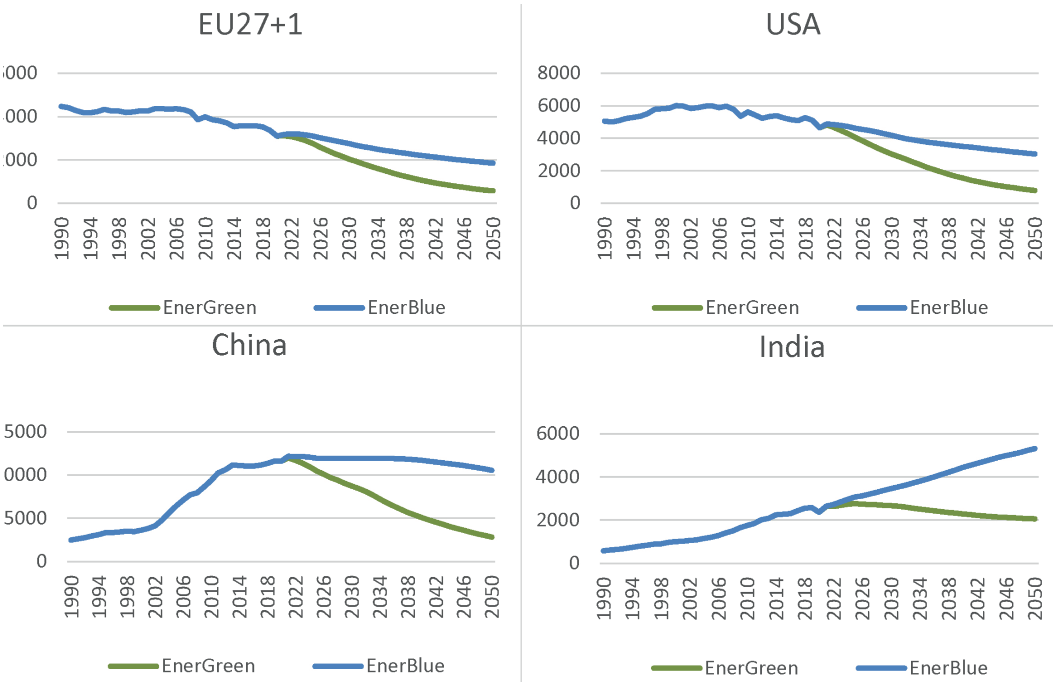

Figure 8. Projected CO_2 emissions in EU27+1, U.S.A., China and India (in Mt CO2)
Source: Enerdata, EnerFuture long-term scenarios, 2020

Limiting the temperature rise to 1.5°C: the case of Europe

The Paris Agreement sets out the global framework to pursue efforts to further limit the temperature increase to 1.5°C. The recent wave of net-zero emission targets' announcements may bring a significant contribution to this objective, if implemented. The following assessment provides a specific focus on Europe carbon neutrality objective by the middle of the century, how it compares to an NDC and a 2°C-scenario, and what sectoral implications are expected.

A 1.5°C-aligned policy commitment in Europe, more precisely a net-zero emission pathway unto 2050, is illustrated in Figure 9. Two main differences appear in comparison with the EnerBlue and EnerGreen scenarios discussed above: on the one hand the very early start of the emissions decrease, as of 2021, and the overall more significant effort over the time horizon. In 2050, the Enerdata-1.5°C scenario reaches 135 $MtCO_2$ of residual gross emissions (including emissions captured by CCS). Where the emission reduction between the NDC and the 2°C pathway is 69%

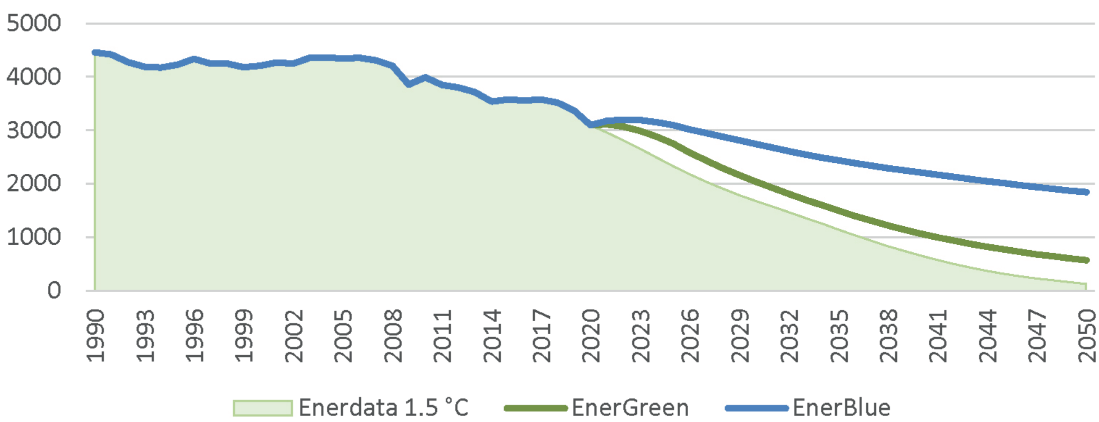

Figure 9. Projected CO_2 emissions in EU27+1(in $MtCO_2$)
Source: Enerdata, EnerFuture long-term scenarios, 2020

in Europe in 2050, the 1.5°C pathway involves a further 24% reduction, necessary to achieve the target. In this scenario, reductions of non-CO_2 gases are also included, amounting to roughly 240 $MtCO_2eq$, mostly CH_4 and N_2O from agriculture. The total residual greenhouse gas emissions in 2050 are expected to be offset by the expected carbon sink provided by the LULUCF (land-use, land-use change and forestry) sector, which is expected to increase slightly in the next 30 years.

From a sectoral perspective, structural inertia and the speed of innovation and technology deployment may lead to significant discrepancies in the contribution to a net-zero emissions objective (Figure 10). At European level, while currently the industry and energy supply sectors today account together for half of CO_2 emissions, these two sectors are expected to be fully decarbonised by 2050, and even to provide net negative emissions. These negative emissions correspond to the contribution of carbon capture and storage by this time horizon, both in the industry and in the electricity generation sector. In such a 1.5°C scenario, the European building sector, both residential households and commercial offices, is also subject to a deep decarbonisation through a range of drivers, including behavioural changes (towards so-called energy 'sufficiency'), stringent policies and incentives in the existing buildings stock and in the regulation for new constructions.

In this net-zero emissions landscape, two sectors appear more difficult to decarbonise, though with a key-role to play. The transport sector would reduce its CO_2 emissions by around 85%, with roughly 140 $MtCO_2$ remaining in 2050, despite the removal of private internal combustion engines from the new vehicle sales shortly after 2040. The agriculture sector would account for a residual 18 $MtCO_2$, (i.e. a 67% reduction compared to 2020), half of it due to energy combustion and the other half from soil amendments and fertilisers. In 2050 however, the bulk of remaining GHG emissions from the agriculture sector are likely to be attributable to CH_4 from cattle and N_2O from soils emissions.

Conclusion: A long way… in a very limited time frame

This quick overview of observed past emissions and required future decarbonisation pathways clearly demonstrates the necessity of adopting a new course in emissions for each of the four major world emitters. In the mature regions, the U.S. and Europe, decarbonisation is already on-going but at a pace that is much too slow.

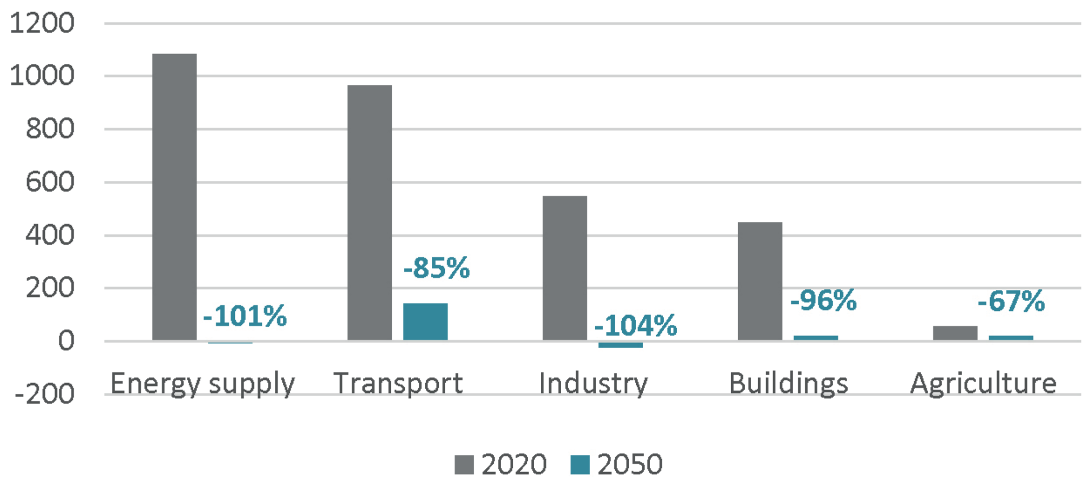

Figure 10. Sectoral CO_2 emission reductions 2020-2050 for a 1.5 °C-compatible EU27+1 (Mt CO_2)
Source: Enerdata, EnerFuture long-term scenarios, 2020

For the largest world emitter, China, the time is decisive: while emissions have been levelling off in the very recent years, it is now time to engage in a rapid decline trajectory and this is clearly required by the new policy of carbon neutrality for China in 2060. As for India, the emissions plateau is still to come but it should take place between now and 2035. Thereafter emissions should also engage in a decreasing trajectory.

Historical experience show that past energy transitions have taken many decades for their full deployment. But on the other hand, IPCC scenarios demonstrate that the game will be over shortly after the mid of this century, that is in thirty years from now. "Accelerated transitions" is thus now a key concept in strategic terms (Sovacool, 2015). And addressing the societal challenge of climate change and energy transitions should become the main research perspective of many scientific and technological endeavours, in a transdisciplinary perspective (OECD, 2020).

References

Grubler, A. (2012). Energy transitions research: Insights and cautionary tales. *Energy policy*, *50*: 8-16.

OECD. (2020). Addressing societal challenges using transdisciplinary research. *OECD Science, Technology and Industry Policy Papers*, N. 88, OECD Publishing, Paris. https://doi.org/10.1787/0ca0ca45-en

Rogelj, J., Huppmann, D., Krey, V., Riahi, K., Clarke, L., Gidden, M., Nicholls, Z., & Meinshausen, M. (2019). A new scenario logic for the Paris Agreement long-term temperature goal. *Nature*, *573*(7774): 357-363.

Smil, V. (2019). *Energy in world history*. Routledge.

Sovacool, B. K. (2016). How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Research & Social Science*, *13*: 202-215.

Suggested citation

Cail, S., & Criqui, P. (2021). Carbon Dioxide Emissions by the Four Largest World Emitters: Past Performance and Future Scenarios for China, U.S.A., Europe and India. *EAERE Magazine*, 11.