Creating Opportunities

Economic Watch

How likely are decarbonization targets? A data-driven approach

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Executive summary

- Achieving the Paris Agreement temperature target implies an unprecedented global decarbonization effort in terms of intensity and persistence over-time. However, in different countries and periods, they have previously experienced great decarbonization efforts as a by-product of policies directed to reduce the dependency on oil and industrial pollutants.
- That is, history provides homologous situations to the decarbonization that we are currently facing, which allows an empirical approach to analyze the effects that standard changes or technological shocks had in CO2 emissions in the past, and hence, assess if shocks of similar magnitude could be sufficient to reach the Paris Agreement's target.
- This approach takes the form of a Vector Autoregressive Model, capturing the historical pattern of interrelationships between GDP and CO2 emission annual growth rates for a specific country. Thus, from the historical pattern of interrelationships, the probability distribution of all the possible future paths of CO2 emissions (either conditioned or not to a given baseline scenario for GDP growth) is extrapolated.
- It is worth noting that the model allows for permanent stochastic changes in GDP and CO2 levels, caused by technology, standards or prices.
- The results from the sample of countries analyzed indicate that in the light of historical evidence, i.e. with the historical combination of decarbonization shocks, net-zero pathways are unfeasible (or highly unlikely) given the expected GDP growth paths. Furthermore, the materialization of the Nationally Determined Contributions (NDC) can be considered, in general, a tail event.
- The conclusions do not change when the model gives room to lower GDP growth scenarios either, indicating that only the use of unprecedented policy instruments, like a global carbon tax, can make net-zero scenarios possible.

1. Introduction

With climate change being one of the hot topics on the global policy agenda, **intensive action to fight global warming and its effects is expected.** In this context, if the Paris Agreement's targets on emission abatement are honored, the international economic landscape could be on the verge of experiencing a major disruption. As stated by Barrutiabengoa et al. (2021) a **common perspective from which looking at the challenge of global warming is the need of decoupling economic progress or welfare from GHG** (or, at least, CO2) emissions, which is in fact the perspective adopted by the Sustainable Development Goal No. 8 (SDG 8.4). Thus, **the emissions of a country can be decomposed** into (Baumert, Herzog and Pershing, 2006):

$$EMISSION_{i,t} = \underbrace{\left(\frac{EMISSION_{i,t}}{ECONOMY_{i,t}}\right)}_{emission\ intensity} \times ECONOMY_{i,t} = \underbrace{\left(\frac{EMISSION_{i,t}}{ENERGY_{i,t}}\right)}_{energy\ dirtiness} \times \underbrace{\left(\frac{ENERGY_{i,t}}{ECONOMY_{i,t}}\right)}_{energy\ efficiency} \times ECONOMY_{i,t}$$

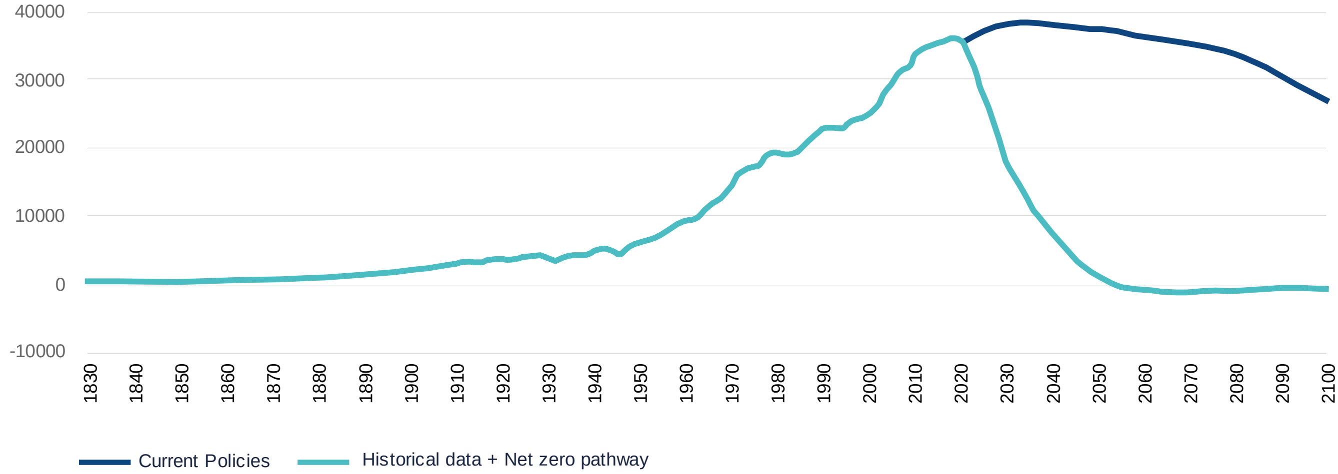
where ECONOMY refers to some aggregate measure of the set of economic activities (or its outputs) of the residents of the country (denoted by i) and the period (denoted by t) under consideration, while EMISSION indicates the GHG emissions associated with that set.

The identity above shows that from a country perspective, **the reduction of GHG emissions requires either the downsizing of ECONOMY (and henceforth, living standards), or a decoupling between ECONOMY and EMISSION**. The latter is equivalent to **reducing the emission intensity**, either by using cleaner energy sources (i.e., reducing energy dirtiness) and/or by increasing the energy efficiency of the production processes. Not surprisingly, confronted with this dilemma, national governments have opted for the decoupling alternative, that is, focusing their environmental efforts on reducing emission intensities without sacrificing economic progress. This is one of the reasons that explain why many countries have explicitly formulated their Nationally Determined Contributions (NDC) in terms of country-wide emission intensity indicators and why these indicators play an essential role in the discussions and negotiations among countries for arriving to environmental agreements (like the Kyoto Protocol of 1997, the Paris Agreement of 2016, or the expected Glasgow Agreement of November 2021).

However, the **decoupling and degrowing alternatives cannot be considered independent.** That is, no free lunch exists in reality, and hence, using technology, institutions and public policies for inducing permanent reductions in GHG emission intensity has a cost in terms of GDP - higher in the extent that carbon pricing policies are not accompanied by green supply policies (IMF, 2020) -. This cost can be understood as a **green premium** (Gates, 2021) and arises from using more costly energy sources that decrease productivity, at least, in the short-run. Therefore, **avoiding a green premium seems unlikely**, with both theoretically constructed models such as dynamic stochastic general equilibrium models and data-driven models such as SVARs pointing in the same direction, especially once the magnitude of the unprecedented emission reduction pathways is taken into account.

The Paris Agreement's objectives specify that global warming needs to be stopped at a maximum of 2 degrees Celsius above pre-industrial levels, aiming at a **1.5 degrees Celsius increase** if possible. In this context, several Paris compliant scenarios have been developed by different institutions, with the scenarios developed by the IEA and NGFS standing out above the rest as references for analysis. These benchmark scenarios are labelled as Net-zero and they aim to achieve an overall balance between emissions produced and emissions taken out of the atmosphere in 2050, requiring an unprecedented decoupling effort. As an example, in the NGFS's Net-zero pathway, the required decrease in total CO2 emissions over the next 20 years is equivalent to the accumulated increase in the last 70, meaning that world emissions would have to be cut over the next 10 years by c.40%-50% to be on the path to reach net-zero emissions by 2050 (see Figure 1 below). Therefore, the objective of this Economic Watch is to illustrate that **the required decoupling challenge calls for innovations and policies of unprecedented nature and scale** in order to be successful. For that, by analyzing the required reductions and future GDP growth, the **work assesses the plausibility of meeting specific emission pathways** based on historical evidence and illustrating the results with individual fan-charts for a sample of countries. All in all, the work provides an **additional tool for assessing if climate targets could become a constraint for future GDP growth**.

Figure 1. **World. CO2 human emissions** (Giga TM CO2)



Source: BBVA Research based on **NGFS**, June 2021.

2. Why is history relevant

Although direct and explicit global decarbonization efforts started with the Kyoto Protocol (effective since 2005) and the Paris Agreement (effective since 2016), there have **previously been great and prolonged decarbonization efforts as a by-product** of the attempts directed to reduce the dependency on oil and industrial pollutants. That is, history provides homologous situations to the one currently facing, laying us a tool to analyze the effects that standard changes or technological shocks had in CO2 emissions in the past, and hence, assess if shocks of similar magnitude could be sufficient to reach the Paris Agreement's goals.

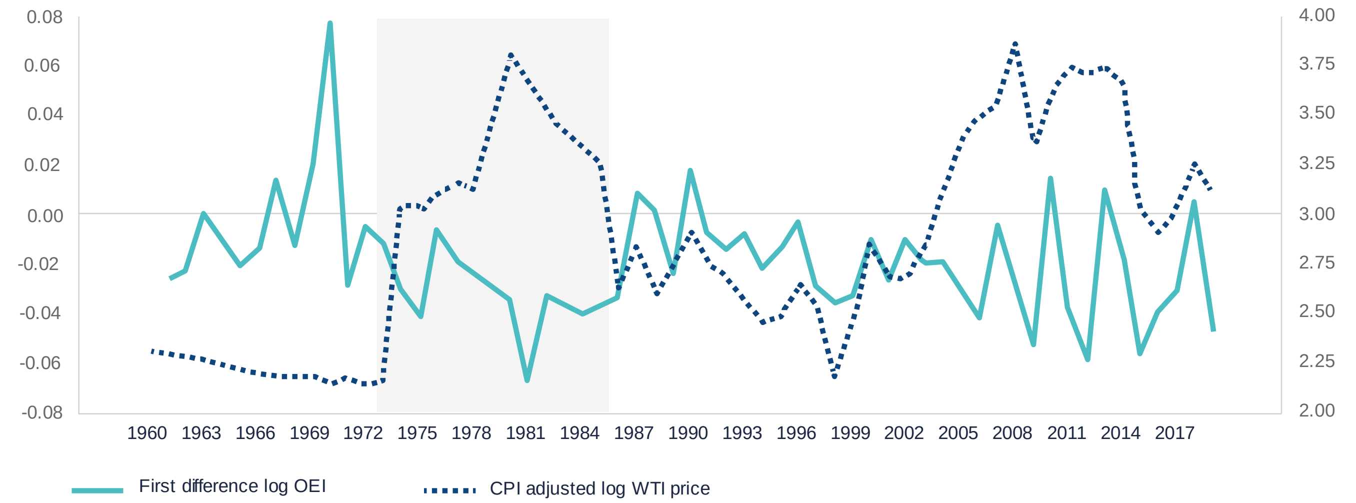
The Oil Embargo (1973) and Iran Revolution (1979) caused a collapse in the expected reliability of the world oil supply (concentrated at the time in the Middle East), motivating the great western industrial powers to decidedly advance actions in multiple fronts for reducing the oil intensity of their economies: new industrial standards (e.g.: USA's CAFE), gasoline taxes, research support (EIA, IEA) and investment on alternative energy sources (nuclear, renewables). As Ross (2013) stated in his work "How the 1973 Oil Embargo Saved the Planet", for oil-importing countries, the 1973 oil shock triggered years of inflation and stagnant growth, together with a widespread belief that the world was running out of oil. Therefore, in the space of just a few years, Americans went from believing that oil would remain cheap forever to believing it would soon run out, and consequently, the U.S. government's response was bipartisan and far-reaching.

President Nixon pushed emergency conservation measures through Congress, including a nation-wide 55-mile-per-hour speed limit, while President Gerald Ford signed legislation that established mandatory fuel economy standards. Bipartisan support for research on energy and conservation was equally important; from 1973 to 1979, federal research funds rose sevenfold. Of course, none of these policies or programs was designed to reduce carbon emissions, as few policy makers took climate change seriously, but probably **these policies did more to curb carbon emissions than any policies after the embargo** (Ross, 2013).

Furthermore, as early as the 1960s, growing evidence regarding the adverse effects of air pollutants on human health boosted legislation on developed countries to restrict the emissions of industrial processes and transport, which as a by-product directly or indirectly limit GHG emissions.

These facts are empirically reflected in the **presence of a stochastic trend in the time series of the CO2 emission intensity (**CO2/GDP) in logarithmic terms for the US and the rest of the countries considered. As it is shown in the section 3 of the work, standard tests cannot reject the unit root hypothesis with annual data from 1960 to 2019, implying that the **emission intensity ratio had experienced numerous stochastic permanent changes along the period such as those expected from technological and institutional innovations** (also from natural or accidental changes in the quality of the oil mix available). Figure 2 below (first difference of the USA intensity ratio) shows that the USA started to decrease its emission intensity ratio after reaching a maximum in oil production in the year 1970 and has been decreasing since in a secular pattern. However, **the effect that the Oil Embargo and the Iranian war had in the decade of the 70s and the actions taken to decrease oil dependency clearly increased the decarbonization rhythm in the country**, which later lost strength due to historically low (and persistent) oil prices that reversed part of the efforts made previously.

Figure 2. **USA. Output-side Emission Intensity ratio evolution (1960-2019).**



Source: BBVA Research.

3. Methodology

In order to construct the CO2-GDP fan-charts, Gross Domestic Product (GDP) and Carbon dioxide (CO2) data were obtained for a sample of countries. In addition to historical data, reference CO2 pathways (Current policies, NDC and Net-zero) and GDP estimates have been retrieved, the former for the purpose of conditioning simulated CO2 pathways and the latter to assess the feasibility of achieving reference emission reduction targets. The total period covered ranges from 1960 to 2030.

Future GDP growth statistics respond to BBVA Research's estimates on April 31st, 2021, while missing historical GDP data have been retrieved from the World Bank's database. On the other hand, historical and projected CO2 data have been mainly obtained from the Climate Action Tracker website, although the NGFS database has been also used to acquire future CO2 pathways consistent with the 1.5 degrees scenario (see Appendix 1 for further details regarding used data).

Taking a closer look at the emission pathways presented in the fan-charts to assess their likelihood, three different paths have been considered. **Current Policy** scenarios assume that existing climate policies remain in place, and there is no strengthening of ambition levels of these policies in the future. **Nationally Determined Contribution (NDC)** trajectories, which can be defined as non-binding national plans highlighting climate action, assume that current pledges are implemented fully, and their respective targets on emissions in 2030 are reached. Note that NDCs are established independently by the governments and although their collective aim is to increase climate ambition, not all NDCs are in accord with the 2 or 1.5 degrees objective. Finally, the **net zero scenarios** foresee global CO2 emissions to be at net-zero in 2050, restricting global warming to 1.5 degrees and meeting the Paris Agreements' objectives.

The methodology summarizes in a **Vector Autoregressive Model (VAR)** the historical pattern of interrelationships between GDP and CO2 emission annual growth rates for a specific country. Thus, from the **historical pattern of interrelationships, the probability distribution** (represented as a fan-chart) of all the possible future paths of CO2 emissions (either conditioned or not on the baseline scenario for GDP growth) is extrapolated. These fan-charts serve as the basis for assessing the consistency of any CO2 emission scenario of interest.

Being more precise, a Vector Autoregressive Model (VAR) for the **first difference** of the log of GDP and CO2 emissions is estimated by OLS using annual data for the period 1960-2020 (for each country)[1,2].

$$\begin{pmatrix} \Delta lgdp_t \\ \Delta lco2_t \end{pmatrix} = \begin{pmatrix} b_{10} \\ b_{20} \end{pmatrix} + \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} \begin{pmatrix} \Delta lgdp_{t-1} \\ \Delta lco2_{t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix}$$

$$\alpha_{i,t} \sim N_1(0, \sigma_i) \text{ for i} = 1{,}2$$

$$\begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix} \sim N_2[0, \Omega]$$

1: Standard tests cannot reject either the hypothesis of the presence of one unit root in (the logs of) GDP and CO2 emissions, nor the hypothesis of no cointegration.
2: The Akaike Information Criterion was used (restricted to a minimum of 1 and a maximum of 5).

As previously stated, a distinctive characteristic of the methodology is that the model implicitly assumes (supported by standard test results) that **GDP and CO2 levels experience permanent stochastic changes** captured by the stochastic time varying intercepts of the VAR in levels (given by α1t y α2t). These intercepts capture past institutional and technological innovations with permanent effects on the CO2 emission intensity as the ones highlighted in section 2 of the work. That is, **the presented model catches all the shocks on the emissions intensity level seen until now; permanent (structural) impacts from the whole set of policies (regulations, changes in oil prices, tax ...).**

$$\begin{pmatrix} lgdp_t \\ lco2_t \end{pmatrix} = \begin{pmatrix} \alpha_{1,t} \\ \alpha_{2,t} \end{pmatrix} + \begin{pmatrix} c_{10} \\ c_{20} \end{pmatrix} T + \begin{pmatrix} c_{111} & c_{121} \\ c_{211} & c_{221} \end{pmatrix} \begin{pmatrix} lgdp_{t-1} \\ lco2_{t-1} \end{pmatrix} + \begin{pmatrix} c_{112} & c_{122} \\ c_{212} & c_{222} \end{pmatrix} \begin{pmatrix} lgdp_{t-2} \\ lco2_{t-2} \end{pmatrix} + \begin{pmatrix} \nu_{1,t} \\ \nu_{2,t} \end{pmatrix}$$

$$\begin{pmatrix} lgdp_t \\ lco2_t \end{pmatrix} = \begin{pmatrix} \alpha_{1,t} \\ \alpha_{2,t} \end{pmatrix} + \begin{pmatrix} c_{10} \\ c_{20} \end{pmatrix} T + \begin{pmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{pmatrix} \begin{pmatrix} lgdp_{t-1} \\ lco2_{t-1} \end{pmatrix} + \begin{pmatrix} \nu_{1,t} \\ \nu_{2,t} \end{pmatrix}$$

$$\alpha_{1,t} = \alpha_{1,t-1} + \mu_{1,t}$$
$$\alpha_{2,t} = \alpha_{2,t-1} + \mu_{2,t}$$

$$\mu_{i,t} \sim N_1(0, \sigma_i) \text{ for i} = 1,2$$

$$\begin{pmatrix} \nu_{1,t} \\ \nu_{2,t} \end{pmatrix} \sim N_2[0, V]$$

In a technical detail, note that the time-constancy of impulse-response functions that the model assumes does not rule out from the model the possibility of capturing the kind of technology shocks required for the decoupling between CO2 and GDP, a must for increasing the CO2 efficiency of GDP. This could be better understood with the following assertions:

First, given that in our model the variables are expressed in logarithmic terms, the impulse-response functions represent elasticity (i.e., the percentage variation of one variable to a 1% change in the other). Second, the constancy of the elasticity is perfectly compatible with a stochastically time varying “average CO2 emitted per unit of GDP” (Mean-CO2) and stochastically time-varying “CO2 emitted by an additional unit of GDP” (Marginal-CO2). In fact, the impulse responses only impose the constancy of the ratio that derives from the division of Marginal-CO2 and Mean-CO2, which is by definition the CO2 elasticity of GDP. Third, what decoupling requires is stochastically time-varying Mean-CO2 and Marginal-CO2 and that is precisely what is implied by the stochastic variability of the intercepts, whereas **the constancy of impulse-responses only implies that the stochastic changes in Mean-CO2 should be proportional to the stochastic changes in Marginal-CO2**.

$$\varepsilon = \frac{\Delta CO2}{CO2} \div \frac{\Delta Y}{Y} = \frac{Y}{CO2} \times \frac{\Delta CO2}{\Delta Y}$$

$$\frac{\Delta CO2}{\Delta Y} = \varepsilon \times \frac{CO2}{Y}$$

In short, **the presented model is an almost fully agnostic empirical approach able to be applied across different economies with minimum requirements of data or idiosyncratic assumptions**. It is worth noting that the presented model fits the research question, guessing the likelihood of alternative future pathways of emissions given the available information, namely long term shocks that shape the joint historical evolution of emissions and GDP.

Therefore, by producing stochastic simulations from the previous VAR, either unconditionally or conditioned on some GDP growth path, **the fan-chart representation of the probability distribution of the conditional or unconditional forecasts** can be obtained. Roughly speaking, each colored area (distinct shade of red) represents a group of emission paths with a probability of 11.1%, with the tone intensity indicating the likelihood of the individual paths of the group (so that the most intense red comprehends the smallest group of paths with the highest individual likelihood). Two different fan-charts are produced in the work, a conditional fan-chart and an unconditional one.

The conditional fan-chart indicates how likely an emission path is given a particular path for GDP growth, whereas the unconditional fan-chart indicates how likely an emission path is if we allow for even the lowest GDP growth path with historical precedent.

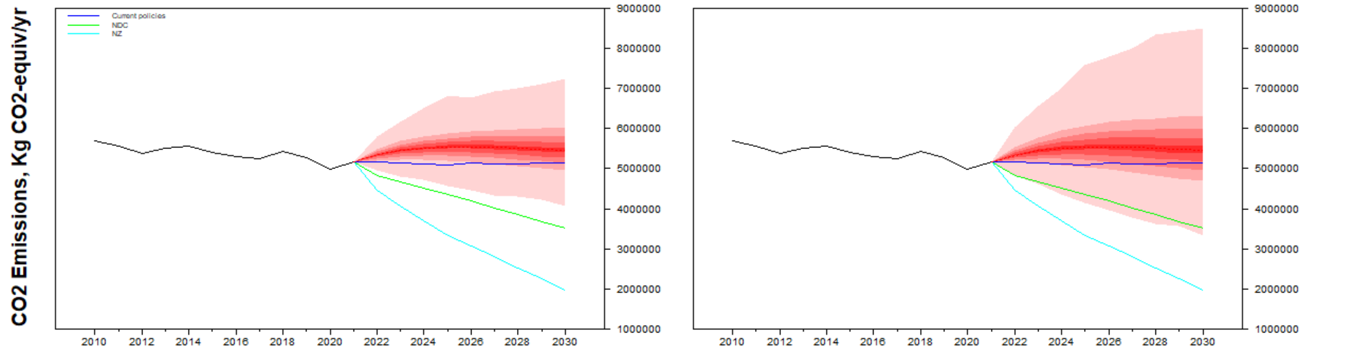
4. Results

The following section summarizes the general results of the study and includes 3 country-specific examples (Argentina, China and USA) in order to illustrate both the final output and the results more clearly. That is, Argentina, China and the USA are shown as representative examples of wider groups.

In short, the results from the sample analyzed indicate that in the light of historical evidence, **net-zero pathways are impossible (or highly unlikely) to reach with GDP growth paths at the levels currently expected**. This result does not change when the model gives room to lower GDP growth scenarios either, indicating that only the use of unprecedented policy instruments, like a global carbon tax, can make ambitious or net-zero scenarios possible. What is more, with GDP growth paths at the levels currently expected, **the materialization of the NDCs can be considered, in general, a tail event.** Regarding NDCs, three big groups can be differentiated:

The first category is composed of **countries with significantly restrictive NDCs** (see Figure 3 for the USA as an example). This group of countries show an unprecedented climate ambition, and hence, to reach its NDCs is highly unlikely or even not possible given both the expected GDP growth and the historical shocks on emission intensities. For these countries, as it can be seen in Figure 3 below, even the unconditional fan-chart describes the NDC pathway as a tail event (but possible to reach with lower GDPs than the ones assumed in the baseline scenario).

Figure 3. **United States of America, CO2 pathways (2010-2030).**
GDP growth restricted to baseline (left) and GDP growth unrestricted (right).

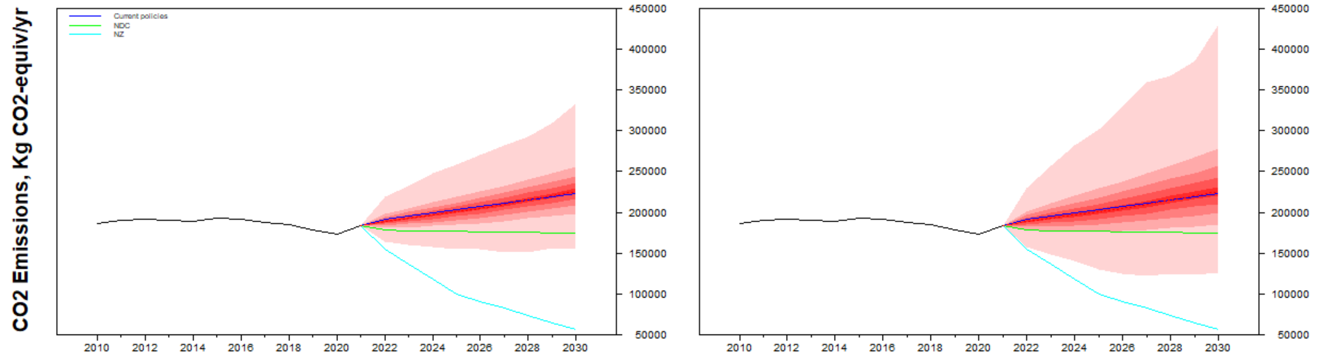


Source: BBVA Research.

The second group is composed of countries that, although they have emission reductions contemplated in their conditional **NDCs, these are not as ambitious as the previous**, at least until 2030 (see the fan-charts for Argentina as an example).

Figure 4 below shows that NDC pathways are tail events for these countries when GDP forecast is conditioned, but unlike in the case of the first group, the possibility of meeting them exists. As before, when lower GDPs than the ones in the baseline are permitted, the prospects of reaching the pathways increase. Note that t**he plausibility of reaching the NDC decreases as climate ambition increases**. That is, countries with higher emission reductions contemplated in their NDCs show less possibilities to reach their objectives.

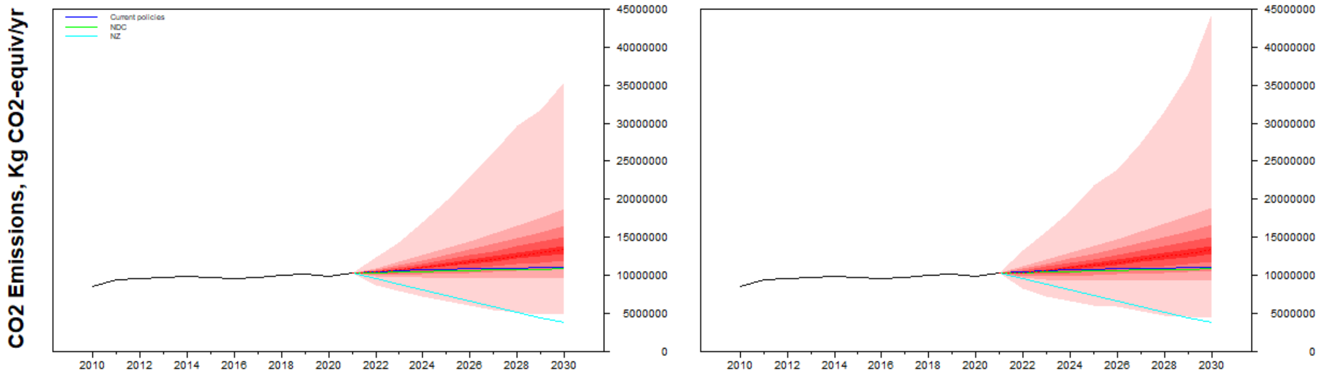
Figure 4. **Argentina, CO2 pathways (2010-2030).**
GDP growth restricted to baseline (left) and GDP growth unrestricted (right).



Source: BBVA Research.

Finally, **the last group is composed of countries with low climate ambition, at least, until 2030** (see Figure 5 for China as an example). The distinctive characteristic of this group is that their NDCs do not contemplate any significant shift in the emission trajectories until 2030 and hence, reaching the objective is more plausible than for the other two group categories, even when the model restricts GDP to the baseline.

Figure 5. **China, CO2 pathways (2010-2030).**
GDP growth restricted to baseline (left) and GDP growth unrestricted (right).



Source: BBVA Research.

All in all, even giving room to much lower GDP growth scenarios, **reaching net-zero emissions looks impossible in the light of history (even NDCs are tail events in the majority of the cases), suggesting that only the use of unprecedented policy instruments, like a global carbon tax, can make these scenarios possible.** Put another way, based on historical evidence, the Economic Watch assesses the plausibility of meeting the emission pathways with the baseline GDP growth paths and suggests that **if unprecedented technological or standard shocks are not induced, climate ambition could become a constraint for future growth if priorities are shifted and reaching climate targets becomes preferential**.

Appendix 1: Data sources and description

In order to construct the CO2-GDP fan-charts for the analyzed countries, Gross Domestic Product (GDP) and Carbon dioxide (CO2) data were obtained for a sample of different countries representative of diverse levels of development and CO2 emission intensity. In addition to historical data, reference CO2 pathways (Current policies, NDC and Net-zero) and estimated GDP have been retrieved, the former for the purpose of conditioning simulated CO2 pathways and the latter to assess the feasibility of achieving reference emission reduction targets. The total period covered ranges from 1960 to 2030.

GDP statistics respond to the BBVA Research mid-term perspectives for baseline scenarios. Missing historical GDP data have been completed using the World Bank's database (here). Note that real GDPs are required to perform the analysis and annual variations are used to fit projected GDP into World Bank's GDP series (constant 2010 US$).

On the other hand, CO2 data have been mainly obtained from The Climate Action Tracker (here). The Climate Action Tracker (CAT) is an independent scientific analysis that tracks government climate action and measures it against the globally agreed Paris Agreement aim of "holding warming well below 2°C, and pursuing efforts to limit warming to 1.5°C." A collaboration of two organizations, Climate Analytics and New Climate Institute, the CAT has been providing this independent analysis to policymakers since 2009. Thus, The Climate Action Tracker recollects and provides Current Policies and NDCs pathways until 2030, together with historical emission figures since 1990. Hence, emissions data for the sample countries have been obtained from CAT and completed (1960-1990) using the Global Carbon Project (here). The Global Carbon Project provides CO2 statistics for all the sample countries (since 1960) in million tonnes of carbon per year, and hence, for values in million tonnes of CO2 per year, one needs to multiply the figures by 3.664 - the full details of the emission measurement method are described in Friedlingstein et al (2020) -. Note that only territorial fossil CO2 emissions are contemplated in the dataset mentioned and therefore, by construction, emission figures cannot take negative values. That is, emissions are mainly based on energy statistics and cement production data and they only incorporate those emissions taking place within national territory (energy and industry production). Again, in order to fit CAT's historical and projected emission data into the Global Carbon Project's CO2 series, annual percentage variations have been used. In the case of some specific countries, as no CAT details were available, other country specific databases have been used in order to obtain the required emissions pathways.

Finally, net-zero pathways for all the countries have been retrieved from the NGFS Scenario Explorer portal (here) using the reference Integrated Assessment Models. **Note that multiple valid net-zero pathways can be obtained in different reference institutions, and hence, the trajectories may change with the specific models and assumptions used**. However, The Network for Greening the Financial System (NGFS) can be taken as a valid reference as it is composed of almost a hundred central banks and financial supervisors that aim to share best practices and contribute to the development of environment and climate risk management in the financial sector.

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