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Making it happen:

national pathways to net zero

DDP IDDRI

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Executive Summary

THIS REPORT PROVIDES BENCHMARKS TO ASSESS GLOBAL PROGRESS TOWARDS NET ZERO, BASED ON COUNTRY PERSPECTIVES

The year 2025 is a pivotal moment for climate action. Current global ambitions and the concrete actions being implemented are insufficient to put the world on track with the goals set by the Paris Agreement, which aims to limit the global temperature increase to "well below 2°C/1.5°C". In 2025, COP30 in Brazil will mark the 10th anniversary of the Paris Agreement and conclude its second cycle of ambition with expected submissions by countries of enhanced Nationally Determined Contributions (NDCs). Demonstrating clear progress on collective ambition during this occasion is vital to ensure that the window for reaching the global objectives remains open, and to maintain positive momentum in international processes. As countries and the global community prepare for this significant moment, they need clear benchmarks that are firmly anchored in science and tailored to the specificities of national circumstances to guide their decisions and actions.

This annual report by the Deep Decarbonization Pathways (DDP) initiative contributes to this collective effort by providing insights into long-term strategies and actionable measures for achieving net zero. It analyses detailed scenarios from ten countries that collectively represent nearly half of the world's population and more than half of global emissions: Argentina, Brazil, China, India, Indonesia, Mexico, Nigeria, Senegal, South Africa, and the United States. Based on in-country perspectives from local experts, these national pathways explore conditions for countries to reach carbon neutrality by 2050-2070 in a manner that aligns with their socio-economic priorities.

The focus of the report is the cross-country insights that emerge from the analysis of these national pathways to net zero. The validity of these insights extends beyond the specific countries from which the analysis is derived; they can serve as benchmarks against which global progress towards net zero can be assessed.

LONG-TERM TRANSFORMATIONS IN NATIONAL PATHWAYS TO NET ZERO

National pathways to net zero involve a relentless decrease in the direct use of fossil fuels by 2050 and beyond, while remaining compatible with domestic socio-economic priorities. Although patterns of energy use vary by country, all show a significant decrease in the share of fossil fuels in energy uses. The result is a notable decline in the total volume of fossil fuel use by 2050, with an acceleration of this reduction thereafter. These trends necessitate country-specific shifts in infrastructure and organizations to reduce energy demand for development objectives. In addition, the deep electrification of most end uses – such as in residential usages, the transportation of people and goods, and production processes – will be essential.

The urgent need to substantially decrease the use of fossil fuels is underscored by the limited contribution of Carbon Capture and Storage (CCS) to the reduction of cumulative emissions until 2050. This limitation arises from geological, technical, spatial and economic constraints that restrict its potential in many countries, as well as obstacles affecting the timing of its deployment.

Despite differences across countries, all national pathways to net zero include net negative CO_2 emissions from the land use sector by 2050. Indeed, this sector is unique in its capacity to generate negative emissions without the need for additional technologies, primarily through reforestation/afforestation and improved management of standing forests. Country-specific approaches are needed to make this mitigation role compatible with other core functions of the sector, such as food production or biodiversity preservation.

Finally, while actions on CO_2 are essential for achieving net zero, non-CO_2 gases must not be overlooked. In the energy sector, most non-CO_2 emissions are addressed through measures primarily aimed at reducing CO_2 emissions, because they share common sources, namely fossil fuel production and consumption. However, the situation is very different in agriculture, where non-CO_2 emissions have different sources from CO_2 emissions. This divergence necessitates targeted, dedicated actions, grounded in a country-driven approach to transforming the agricultural sector.

IMMEDIATE ACTIONS IN NATIONAL PATHWAYS TO NET ZERO

Actions and strategies are often assessed according to their immediate impact on emissions. However, a critical function of short-term actions is to facilitate the necessary transformations for the long-term. For activities that encounter inertia – resulting in a time lag between the implementation of a specific action and its tangible impact on emissions – short-term actions should focus on the sources of this inertia. These sources include infrastructure and technology, governance and institutions, and lifestyle and behaviour change. These short-term actions may not deliver immediate emission reductions, but they are essential to lay the foundations for the long-term changes required in each country.

In parallel, rapid emission reductions are needed to set countries on track towards carbon neutrality. National pathways to net zero highlight three sectors with the highest potential for immediate emission reductions, while maintaining the capacity for deeper longer-term reductions: power generation, passenger transport and land use. These three sectors are characterized by the ready availability of commercially viable, technical solutions for CO_2 emission reductions, and the existence of well-defined policies to accelerate their deployment in each country.

Furthermore, national pathways to net zero entail structural changes in economic and industrial systems, driven by the reduction of existing carbon-intensive activities and the concurrent emergence of new industries that supply the goods, technologies and services required for the low-carbon transition. These structural changes will inevitably have a significant impact on key socio-economic dimensions in countries, including employment, investments, and trade. Turning these transformational challenges into opportunities for development requires the determined implementation of national policies to address the specific challenges of each country. The design and implementation of these national policies should occur within a context of a proactive search for mutually beneficial partnerships and innovative approaches to international cooperation to avoid the risk of generating counterproductive competition between countries and undermining their effectiveness in light of global interdependencies.

Finally, the transition to net zero presents socio-economic challenges that require careful management to avoid hindering development in the short term. To this aim, country-specific policy packages should be carefully designed to address the specific challenges of national circumstances. These packages should notably include short-term social and economic policies and actions aimed at preserving the socio-economic benefits of the transition, particularly for disadvantaged and vulnerable populations.

THIS REPORT SERVES AS A TOOLBOX TO GUIDE COUNTRIES AS THEY PREPARE THEIR NDCS

With its cross-cutting insights on national pathways to net zero, this report provides a practical roadmap for all countries striving to achieve the Paris Agreement goals. By showcasing diverse pathways to net zero, it demonstrates that deep decarbonization is not only feasible but can also go hand-in-hand with economic development.

While there is no one-size-fits-all approach to decarbonization, each country can and must find its own path towards carbon neutrality, taking into account its specific circumstances and priorities. However, the needed transformation of energy, industrial, urban and land use systems in different countries forces different countries to address similar challenges. Recognizing these shared challenges, the experiences of the ten countries analysed in this report offer valuable lessons for all nations as they navigate along their own paths towards net zero and explore their opportunities and challenges.

Practically, the cross-cutting insights from this report provide concrete guidelines for implementing the net zero transition at the country level. These insights can be instrumental in guiding countries as they prepare to enhance their NDCs and to engage in the collective discussions on climate ambition in 2025.


DDP

Introduction

COUNTRY-DRIVEN, SCIENTIFIC BENCHMARKS TO GUIDE NATIONAL AMBITION

The preparation of the next round of Nationally Determined Contributions (NDCs) is the key milestone of international climate discussions during the 2024-2025 period. It is an important test for the assumption underlying the Paris Agreement that the gradual ratcheting up of national ambition can progressively facilitate convergence towards the global long-term goal of limiting global warming to "well below 2°C/1.5°C" in the context of sustainable development.

Scientific evidence, underlined by the Global Stocktake, has shown that this long-term goal requires a change of systems, i.e. structural transformations in the socio-economic organization of all human activities, in contrast to past and current trends.[1] When considering short-term decisions and actions, attention should focus not only on their impact on headline emission targets for 2035, but also on whether they effectively put a country on track to implement the necessary long-term transformations. This long-term perspective on short-term actions is essential for planning credible, truly ambitious and actionable NDCs and for evaluating whether country plans are truly aligned with the long-term goals of the Paris Agreement.

Countries therefore need analyses of the long-term transformations that are firmly grounded in scientific evidence and in the specificities of national circumstances, and that can serve as a guide for short-term national decisions and actions. This concept is especially evident in the long-term low-emission development strategies, introduced in Article 4.19 of the Paris Agreement and reiterated since then, as a critical instrument to support ambition.[2] These long-term strategies (LTSs) are the main tool for countries to explore the long-term transformations and consistent short-term actions compatible with Paris Agreement objectives. They involve essential consultations with stakeholders, experts and decision makers to capture the best available science and the specificities of national circumstances, making these strategies country-driven, policy relevant benchmarks for national ambition. This open process makes the LTS concept a practical means of integrating the diversity of national planning processes that typically happen simultaneously in a country, such as those related to economic planning, development, adaptation/ resilience and biodiversity.

Ambitious, practical, and realistic short-term targets and actions, which can be codified in enhanced NDCs, would emerge from integrating insights from these LTSs with constraints on the detailed opportunities for immediate actions, including political economy considerations – such as those emerging from existing *sectoral or national goals, national policy objectives, ongoing cooperation deals, and past socio-economic trends.*

This focus on linking NDCs with LTSs defines a specific approach to the question of the alignment of NDCs with the Paris Agreement goals. It highlights the critical importance of specific national circumstances and the long-term perspective when considering the timeline of emission reductions for the short and medium term. It also reflects the dynamic nature of the process, which requires ongoing interaction between NDCs and LTSs to gradually enhance ambition.

1 https://unfccc.int/documents/631600
2 https://www.iddri.org/sites/default/files/PDF/Publications/Catalogue%20Iddri/Etude/202106-ST0721-LTS%20COP26.pdf

THE DEEP DECARBONIZATION PATHWAYS INITIATIVE

Overview and key principles

The Deep Decarbonization Pathways (DDP) initiative has been established as the primary network for in-depth scientific analysis that supports national long-term strategies .[3]

The scientific literature provides a large amount of information on long-term scenario analysis, as notably summarized in recent AR6 IPCC reports.[4] However, this literature primarily relies on global-scale assessments, which often lack detailed insights and may therefore overlook important country-specific drivers of change that could be important when defining real-world, policy-relevant targets and actions at the national level.

The DDP aims to address this gap by providing a scientific reference for examining the conditions at the country level to simultaneously achieve very low levels of greenhouse gas emissions by 2050-2070 and meet critical socio-economic priorities. The DDP's work combines an analytical component focused on developing country-driven scenarios, and an engagement component that ensures these analyses are effectively integrated into national decision-making processes.

The DDP's work is conducted by in-country research teams, who can select their own methods and hypotheses and ensure that their analysis captures all relevant dimensions of a country's circumstances. These in-country teams are independent from their government but engaged in their national policy processes, in which they contribute scientific insights to decision-making based on their modelling and scenario analyses. Their scientific and policy credibility, rooted in high academic standards and extensive experience with their national policy processes, give a strong legitimacy to the DDP's work as a reference for realistic, ambitious and actionable national transitions.

3 https://ddpinitiative.org/
4 see in particular chapters 3 and 4 at: https://www.ipcc.ch/report/ar6/wg3/

The DDP's work is based on a set of key principles:[5]

- Consideration of the interplay between multiple time horizons, starting from the long-term requirements of Paris-compatible national transitions to inform consistent short-term priority action
- Analysis of the detailed content of transformations at the sectoral level and their cross-sectoral interactions, to generate coherent recommendations on policies and actions at the sectoral and national levels
- Development of several scenarios in each country, to explore the range of potential futures and options for the transition, mapping their differentiated impacts in a non-normative way
- Insertion of national transitions into the global context, to operate a national translation of global benchmarks and identify requirements for international cooperation
- Facilitation of an inclusive and coordinated process to ensure the analysis remains relevant to country-specific circumstances and is appropriated by a diverse range of national actors.

A brief summary of DDP's three phases since 2013

The DDP has conducted three main phases of scenario development since its creation in 2013:

- phase 1 in the initial Deep Decarbonization Pathways project[6] during 2014-2015, in the lead up to the Paris Agreement;
- phase 2 in the DDP-LAC[7], DDP-BIICS[8] and ACT-DDP[9] projects during 2016-2021;
- phase 3 in the IMAGINE[10], NDC-ASPECTS[11] and DDP-Africa[12] projects since 2021.

Each phase represents an evolution from the previous, reflecting changes in both international and national policy discussions, as well as scientific progress in methodologies and scenario design.

5 https://www.nature.com/articles/s41558-019-0442-8
6 https://ddpinitiative.org/wp-content/pdf/DDPP_2015_REPORT.pdf
7 https://ddpinitiative.org/wp-content/uploads/pdf/ddp_lac_en.pdf
8 https://ddpinitiative.org/wp-content/pdf/DDP_BIICS_CountryReport.pdf
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10 https://ddpinitiative.org/ddp-imagine/
11 https://ndc-aspects.eu/
12 https://ddpinitiative.org/ddp-africa/

The DDP has explored different levels of ambition:

- phase 1 focused on a 2°C global temperature goal prior to the Paris Agreement, when this was the scientific basis for the most ambitious scenarios;
- during phase 2, the focus shifted to the goal of "well below 2°C/1.5°C" at a time when analyses started to emerge globally on this objective (particularly in the context of the IPCC SR1.5 report[13]);
- in phase 3, the main emphasis is on the carbon neutrality objective, due to the broad acknowledgement in the scientific literature that this is a necessary requirement to reach the Paris Agreement goals, along with the increasing political endorsement of such national targets.[14]

The DDP has also incorporated an increasing level of sectoral detail in its analyses:

- phase 1 focused on the energy sector as the main global CO_2 emissions source, given that this phase of work was primarily dedicated to international processes and therefore sought global relevance;
- phase 2 introduced a detailed analysis of the agriculture and land use sector when analysing Latin American countries in particular, where this sector was central to decarbonization analysis.[15] This phase also involved sector-specific in-depth analyses of the energy system, with an initial focus on power generation and passenger transport[16], as a core requirement for linking the analysis to national decision-making;
- phase 3 then continues this trend, carrying out a detailed systematic analysis of all critical sectors of deep decarbonization, including the examination of a variety of drivers beyond the technical ones typically addressed in modelling studies.

Finally, the coverage and focus on countries have also evolved over time:

- phase 1 focused on large emitting countries, including an analysis of 16 developed and emerging economies;
- phase 2 shifted the emphasis to large emerging economies and initiated work with other developing countries;
- phase 3 seeks to achieve more diverse coverage, with large emerging countries remaining the core focus, but with the intent to also include industrialized countries and less developed economies within a consistent framework.

13 https://www.ipcc.ch/sr15/
14 https://zerotracker.net/
15 Svensson, J., Waisman, H., Vogt-Schilb, A., Bataille, C., Aubert, P. M., Jaramilo-Gil, M., ... & Villamar, D. (2021). A low GHG development pathway design framework for agriculture, forestry and land use. Energy Strategy Reviews, 37, 100683.

16 Julien Lefèvre, Yann Briand, Steve Pye, Jordi Tovilla, Francis Li, Ken Oshiro, Henri Waisman, Jean-Michel Cayla & Runsen Zhang (2021) A pathway design framework for sectoral deep decarbonization: the case of passenger transportation, Climate Policy, 21:1, 93-106, DOI: 10.1080/14693062.2020.1804817

THE SCENARIOS OF THIS REPORT

Description of the scenarios

This report examines scenario analyses from nine countries: Argentina, Brazil, China, India, Indonesia, Mexico, Nigeria, South Africa, and the United States. We also include insights from the analysis conducted in Senegal, even though the fully developed quantified scenarios are not yet available. These ten countries account for 58% of global GHG emissions in 2023[17] and represent a diversity of country contexts, particularly in terms of critical socio-economic and development issues.

The scenarios outlined in this report can be categorized into two main categories:

- Current Policy Scenarios (CPS), which reflect the pursuit of current trends within a country and serve as a reference point for current national ambitions.
- Deep Decarbonization Scenarios (DDS), which correspond to pathways that explore ambitious emission reductions aligned with the Paris Agreement goals.

17 EDGAR (Emissions Database for Global Atmospheric Research) Community GHG Database (a collaboration between the European Commission, Joint Research Centre (JRC), the International Energy Agency (IEA), and comprising IEA-EDGAR CO_2, EDGAR CH4, EDGAR N2O, EDGAR F-GASES version EDGAR_2024_GHG (2024) European Commission. Crippa M., Guizzardi D., Pagani F., Banja M., Muntean M., Schaaf E., Becker, W., Monforti-Ferrario F., Quadrelli, R., Risquez Martin, A., Taghavi-Moharamli, P., Grassi, G., Rossi, S., Melo, J., Oom, D., Branco, A., San-Miguel, J., Manca, G., Pisoni, E., Vignati, E., Pekar, F., GHG emissions of all world countries – JRC/IEA 2024 Report, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/4002897, JRC138862.

These scenarios belong to the DDP's phase 3 (see above). They represent the most up-to-date set of scenarios developed under the DDP, which integrate over ten years of ongoing refinement in both methodological and policy aspects, and advance the assessment beyond that of previous DDP studies. In particular, the DDS analysed in this report provide a consistent national-level exploration of carbon neutrality (for a more detailed discussion, see the subsection below) and are described with a high level of granularity, particularly at the sectoral level, maximizing policy relevance. These national scenario characteristics that support the study presented in this report enhance its scope beyond previous DDP studies, both in terms of the depth of ambition considered and the breadth of analysis.

Annex 1 provides more detailed information on these scenarios, including the overall narrative of the CPS and DDS scenarios considered, and publicly available references for further details on the country analyses.

The scenarios are based on model results. The calibration dates for these models vary by country, ranging from 2015 to 2022, depending on the availability of national datasets. To ensure comparability, extrapolation ensures a common starting date in 2020 for all figures and quantitative analyses.

The scenarios explore national-level carbon neutrality

To assess the consistency of national DDS scenarios against the global goals of the Paris Agreement, we do not use the standard "burden sharing" approach, particularly because of the impossibility to define an ex-ante allocation of carbon budgets that would be based on a principle of equity that all countries can perceive as fair.

Consistent with the bottom-up paradigm of the Paris Agreement, we adopted a country-centred approach. We focused the analysis on CO_2 emissions, which is the key long-term greenhouse gas that will critically influence global temperature trends. We acknowledge that the Paris Agreement goals require the achievement of global net zero CO_2 emissions between the early 2050s and early 2070s.[18] Considering the significance of the countries included in this study in terms of their CO_2 emissions, it would be essentially impossible to reach global carbon neutrality if any of these countries do not reach very low CO_2 emission levels or "national carbon neutrality" over this period. Therefore, below, we examine how the DDS presented in this report, based on a country-driven perspective, relate to a "national carbon neutrality" approach.

Figure 1 presents CO_2 emissions in DDS for all countries in absolute values and indices (the latter to ensure better visibility of trends in each country). We also present the corresponding changes in CO_2 emissions per capita between 2020 and 2050 to compare efforts across countries (**Figure 2**).

An official political commitment to carbon neutrality has been made by most of the countries analysed in this study (by 2050 for Brazil, South Africa and the US; by 2060 for China, Indonesia and Nigeria; by 2070 for India). In all of these countries, the DDS explicitly considers this objective in the definition of the scenario. Consequently, CO_2 emissions reach net zero (or below) by 2050 in the DDS of Brazil, South Africa and the US. For the other countries, the modelling covers the carbon neutrality dates for China, Indonesia, Nigeria (2060) and India (2070).

In Mexico, even in the absence of an official net zero commitment, the DDS analysed in this study projects net-negative CO_2 emissions by 2050, with a carbon neutrality date of around 2045.

Finally, in Argentina, the DDS does not specifically consider a carbon neutrality goal in the definition of the scenario itself. But the scenario results display a significant decrease in total CO_2 emissions after 2030, from 231 $MtCO_2$ in 2030 to 111 $MtCO_2$ in 2050. A simple extrapolation from this 2030-2050 trend would lead to carbon neutrality being reached around 2065 to 2070. In addition, this scenario includes conservative assumptions regarding the potential for decarbonization in key hard-to-abate sectors (industry and freight sectors), which explain the slowdown

18 Cf SYR SPM B.6.1: "Pathways that limit warming to 1.5 °C (>50%) with no or limited overshoot reach net zero CO_2 in the early 2050s, followed by net negative CO_2 emissions. […]. Pathways that limit warming to 2 °C (>67%) reach net zero CO_2 emissions in the early 2070s"

in the decrease in emissions between 2040 and 2050, as both sectors are key sources of residual emissions. These external assumptions reflect the actual state of policy discussions in the country, particularly concerning the potential for international technological progress. However, more optimistic assumptions could be relevant and enable more ambitious reductions by 2050, therefore paving the way for an acceleration of the trend towards CO_2 neutrality.

The scenarios explore conditions to align deep decarbonization with national socio-economic and development objectives

The DDS places socio-economic development priorities at the forefront, as defined by each country. This ensures that the DDS have strong, explicit assumptions regarding key development objectives in the carbon neutrality context, therefore exploring the conditions for national-level alignment of climate and development objectives. **Figure 3** presents a cross-country comparison of GDP per capita in 2020 and 2050, showing that all countries exceed the 2020 GDP per capita levels for upper-middle-income countries.

Figure 1. Total net CO_2 emissions in DDS scenarios

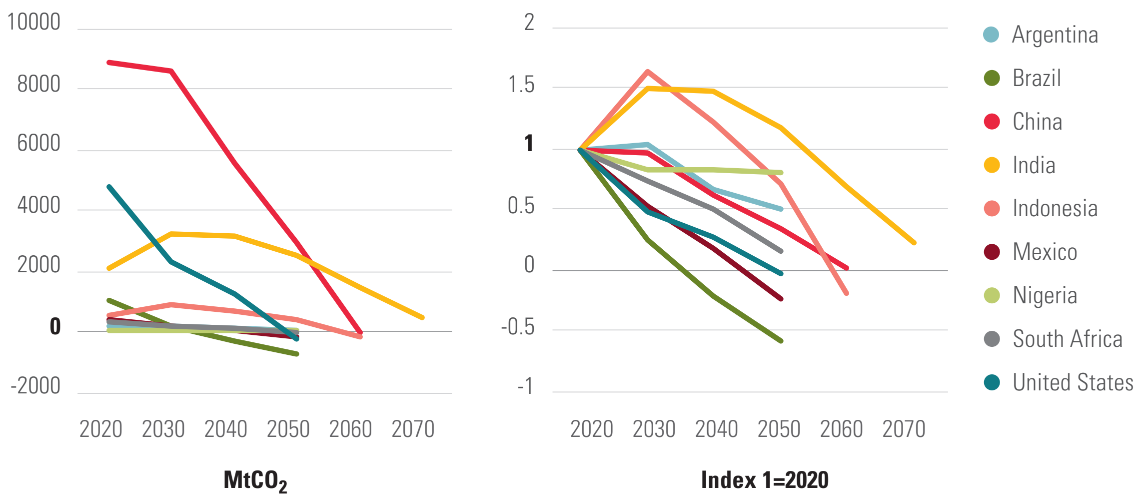
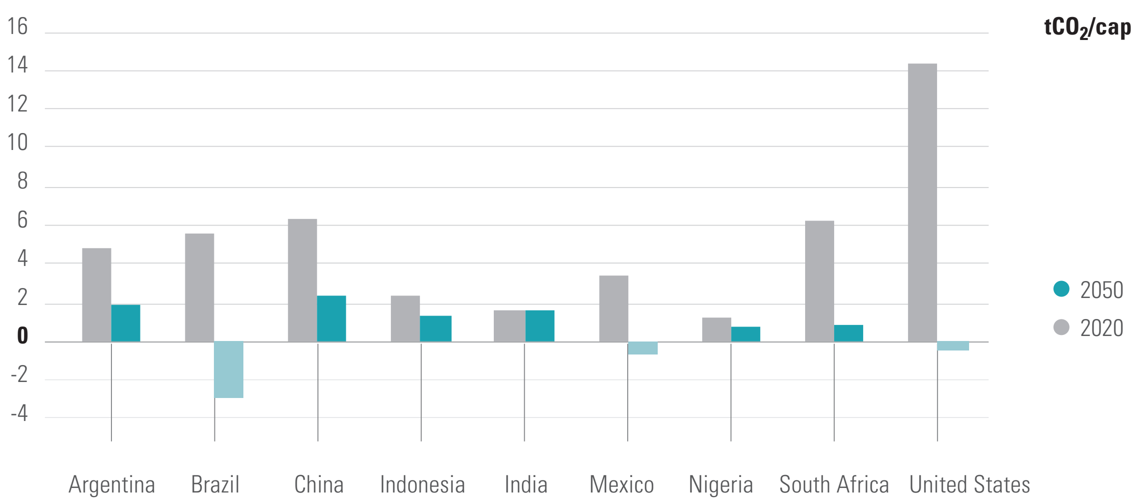


Figure 2. CO_2 emissions per capita in DDS scenarios



Although a commonly used measure of socio-economic convergence, this indicator is however largely insufficient to characterize the socio-economic trends in each country. To provide a more detailed perspective, Annex 2 includes a description of key socio-economic and development narratives in the DDS, organized by country. The specific focus and the detailed results vary by country based on the key priorities that the scenario analysis addresses, which reflect the socio-economic priorities in national policy debates. Importantly, this means that discussions of the DDS encompass not only the significant reduction of carbon emissions but also the achievement of socio-economic and development objectives.

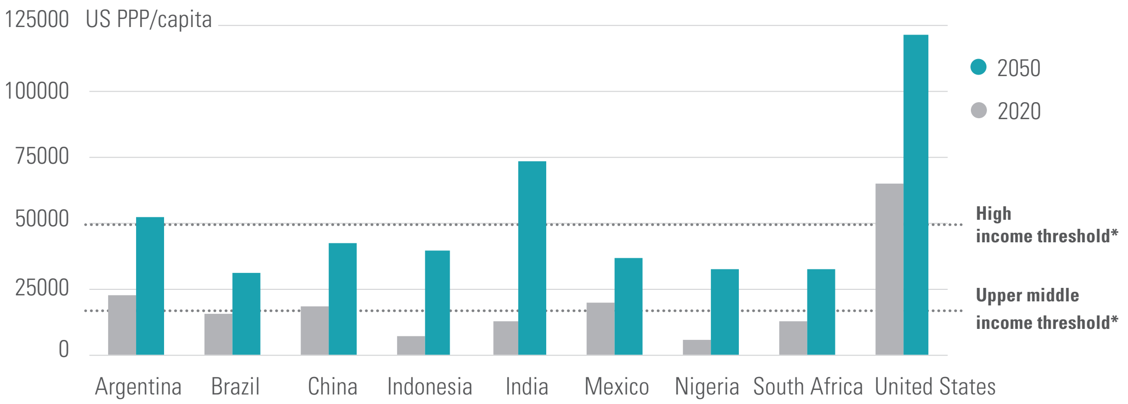
APPROACH AND REPORT STRUCTURE

Based on the core principles outlined above that support their development, the scenarios presented in this report closely reflect each country's circumstances, providing a strong foundation for identifying the conditions necessary for transformations that are consistent with the global goals of the Paris Agreement. Notably, the relevance of these scenarios comes from the scientific and policy credibility of the in-country partners who developed them, rooted in high academic standards and extensive experience with their national policy processes.

This report does not include the detailed analyses for the ten countries examined in this study (country-by-country information can be found in separate documents as listed in Annex 1). Rather, it presents a set of cross-country messages, which can be useful for all countries seeking their own paths towards ambitious climate and development objectives. The messages should not be interpreted as normative recommendations to be followed blindly by all countries; rather, they are intended as guidelines to help countries to structure their reflections and identify their own targets and actions based on their specific circumstances. In practice, the scenario results from the ten countries are used to support the messages through cross-country comparisons of selected indicators that characterize national transitions, as well as detailed case studies that highlight specific aspects of the national transition in one or more countries to illustrate broader arguments.(see the list of figures and case studies at page 6)

The report is divided into two parts. Section 1 analyses long-term transformations in national pathways to net zero, while Section 2 explores the concrete actions that should be taken in the years ahead to set countries on track with these needed transformations.

Figure 3. GDP per capita



** based on 2020 WB data (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD)*

Long-term transformations in national pathways to net zero

Long-term transformations in national pathways to net zero

USE OF FOSSIL FUELS

National pathways to net zero necessitate a relentless decrease in the direct use of fossil fuels by mid century, aligning with domestic socio-economic priorities. These trends particularly require country-driven shifts in infrastructure and organizations to reduce energy needs for development objectives.

Today, everyday activities, such as living and working in buildings, producing goods and services, transporting people and goods, are largely dependent on the use of energy, especially fossil fuels. In most countries, direct fossil fuel use accounts for approximately 70% of national final energy consumption. However, specific country circumstances can lead to different starting points, as demonstrated by Brazil, with its abundant natural resources, and Nigeria, due to the dominant role of traditional biomass (**Figure 4**).

National pathways to net zero focus on how countries can enhance the quality of life for their populations, particularly the most vulnerable, while achieving carbon neutrality. They highlight the need for a significant decline in the share of fossil fuels in energy consumption among the countries studied. (**Figure 4**).

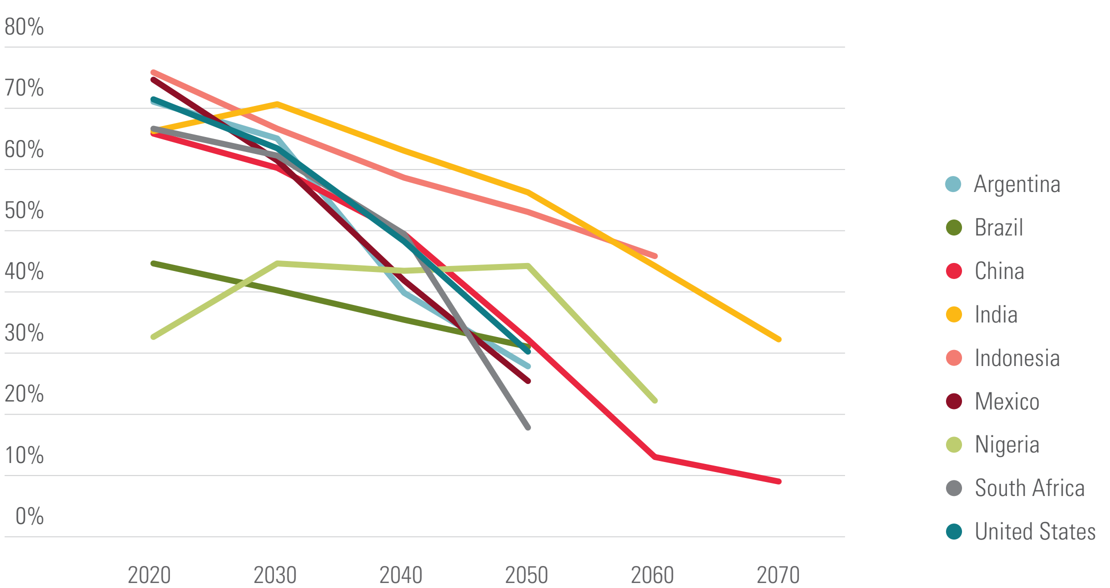
However, these national pathways are not uniform. They vary due to distinct patterns of energy use shaped by the specificities of each country's socio-economic context and energy landscape, as well as their target dates for national carbon neutrality. For instance, some countries are experiencing a steady decline in the share of fossil fuels in energy use, decreasing from around 70% to about 30% or lower. In contrast, India and Indonesia are two examples of countries where this decrease, although steady, is more gradual, largely due to rapid growth in total energy demand in response to significant development challenges and later target dates for carbon neutrality.

Nigeria demonstrates a different situation where the share of fossil fuels will initially increase as the country gains access to modern energy technologies and services, and experiences a surge in energy demand to support domestic development objectives. A reduction in fossil fuel dependence will occur later, after 2050, in a second phase of development when the country can shift towards less reliance on fossil fuels and step up efforts to reduce energy-related emissions to reach the 2060 carbon neutrality goal.

Despite these variations, all countries show a clear structural decreasing trend in the use of fossil fuels for final energy consumption. The limited role of CCS in national pathways to net zero significantly reinforces this need to reduce fossil fuel usage (cf. section - Carbon Capture and Storage).

As a result, there will be a notable decrease in the total volume of fossil fuels used in 2050 compared to 2020 – by around 30% in total across the nine

Figure 4. Share of fossil fuels in final energy consumption (%)



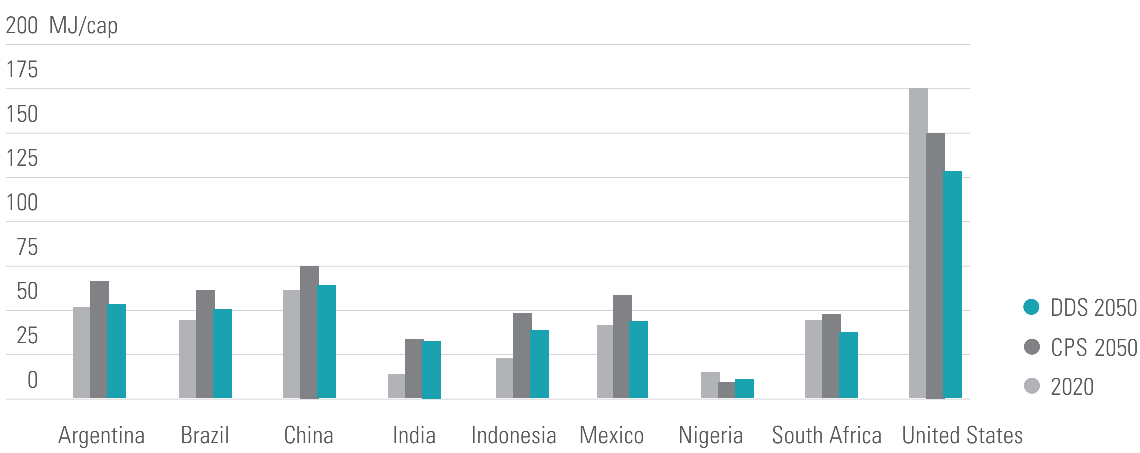
Fossil fuels are coal, natural gas and oil final derivatives. In India, fossil fuel shares have been extrapolated for the years 2060 and 2070 based on Garg et al., 2024. (https://psa.gov.in/CMS/web/sites/default/files/publication/ESN%20Report-2024_New-21032024.pdf) analyzed countries. The shift away from fossil fuels will be only partial in 2050, demonstrating the need for a progressive reduction of fossil fuels to meet development needs. Importantly, the analysis in countries looking beyond 2050 shows that fossil fuel use will continue to decline after that point, and do so even more rapidly, paving the way for progressive but sustained reductions in fossil fuel volumes in the decades ahead.

These national trends, which align the reduction of fossil fuels with domestic socio-economic priorities, particularly energy access, are driven by two main factors.

On one hand, national pathways to net zero, which integrate climate and development objectives within a specific country context, emphasize the need to create development patterns that are less dependent on energy. This decoupling can be seen in the lower energy consumption per capita in DDS as compared to the CPS, across all countries studied , which shows that, all else being equal, decarbonization strategies can help to achieve development objectives with a lower energy input (**Figure 5**). However, these national pathways are not uniform; they vary significantly based on country-specific energy consumption patterns. Most of the countries studied project an increase in energy consumption per capita in the DDS, consistent with socio-economic needs by 2050, although this increase is lower compared to the continuation of current trends of the CPS. In industrialized countries such as the US, energy consumption per capita is expected to decrease due to the saturation of energy access and the dissemination of energy-efficient technologies, with a more rapid decrease occurring under carbon neutrality than if current trends are continued. South Africa serves as an example of a country where systemic shifts in infrastructure and organization, combined with technological progress, can significantly influence energy demand. Indeed, these shifts can outweigh the increased energy needs for development, therefore leading to an absolute decrease in energy use per capita (**Figure 5**).

Systemic shifts in infrastructure and organization are crucial for supporting these trends by enabling development patterns that require less energy to meet domestic socio-economic objectives. In other words, these structural changes will ensure that the future provision of key socio-economic functions, such as mobility, work, consumption, production, and nutrition, can be carried out with lower energy consumption. This shift goes beyond simply replacing energy-consuming systems with more efficient options. For mobility, transformations include integrating the planning of land use and transport infrastructure to improve access to daily activities using low-carbon modes (walking, biking and public transport) and therefore support the shift away from the current dependence on cars and energy-intensive mobility systems (Case study - Structural changes in urban and transport infrastructure and organization).

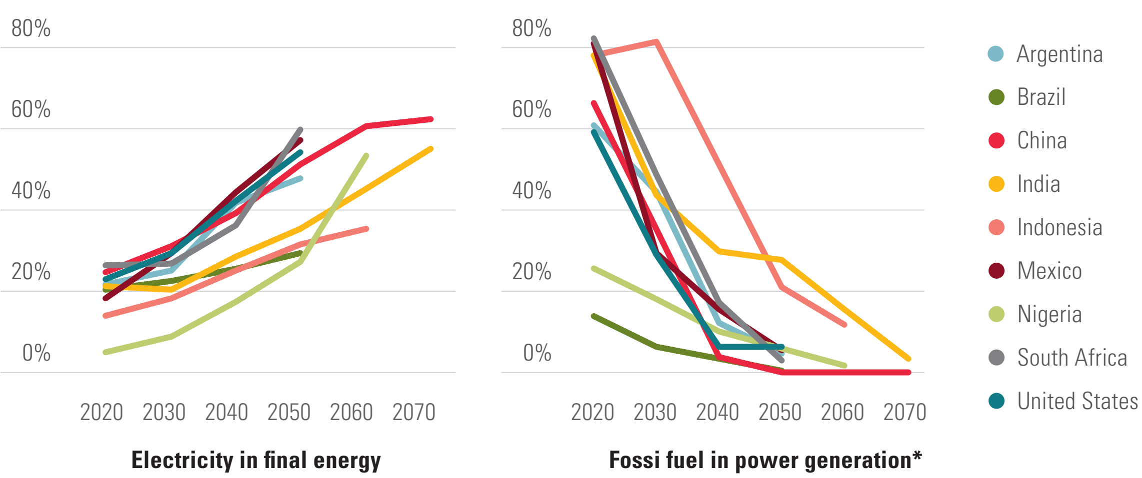
Figure 5. Final energy consumption per capita (MJ/cap)



For residential buildings, the shift requires an emphasis on bioclimatic design to minimize heating and cooling needs or encouraging behavioral changes in energy use at home. In the production and consumption patterns of industry, key changes include the rethinking of product design and industrial processes, as well as changes in consumption behaviors to promote the reduction, repair, reuse and recycling of goods and raw materials.

On the other hand, national pathways to net zero emphasize significant electrification across most end uses in buildings, the mobility of people and goods, and goods production, driven by the adoption of electricity-based equipment (Case study - Examples of end-use electrification). As a result, electricity is projected to become the dominant end-use energy by 2050 in Argentina, China, Mexico, South Africa and the United States and by their national target dates for carbon neutrality in the case of Nigeria and India (**Figure 6**, left). In contrast Brazil and Indonesia are two examples of countries where the electrification of end-uses is more gradual, largely due to the prefered use and availability of biomass and the rapid growth in total energy demand related to significant development challenges. (**Figure 6**, left). This electrification is consistent with carbon neutrality, because national pathways also entail a substantial reduction in fossil fuels for power generation, which is expected to be largely fossil-free by the target date for a country's carbon neutrality (**Figure 6**, right). The limited role of CCS in national pathways to net zero (Section - Carbon Capture and Storage) emphasizes the need to decouple electricity generation from fossil fuels. However, this decoupling will vary according to country-specific trends. For instance, in India, the projected small increase in fossil fuel use in the power sector from 2040 to 2050 (prior to a reduction to almost zero by 2070) results from investments in gas power plants, which are required to rapidly increase renewable capacities and facilitate grid stability.

Figure 6. Share of electricity in final energy consumption and share of power generation from fossil fuels (%)



** this share includes abated and unabated fossil fuel power generation.*

CASE STUDY

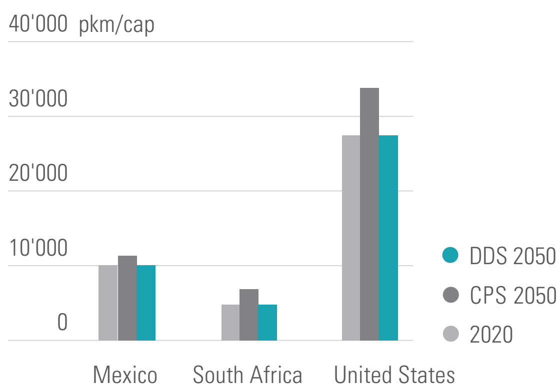
Structural changes in urban and transport infrastructure and organization

In Mexico, South Africa and the US, the analysis shows that structural changes in urban and transport organization could help moderate the increase in per capita mobility, and related energy and emissions, compared to the CPS, while continuing to meet the needs of the population (**Figure 7**).

This is the result of changes in urban planning to better integrate land-use policies, investments in public transport infrastructure and services, as well as economic and regulatory incentives to create more mixed-use neighbourhoods. In these areas, daily necessities such as homes, work, shops, and public services are within short walking distances or bike rides, i.e. accessible by non-motorized transport (NMT), or are easily reachable by public transport (PT). However, optimizing the spatial distribution of human activities must be complemented with revised investment in NMT and PT infrastructure, as well as regulations and incentives that promote these modes of transport and develop services while limiting car use.

Ultimately, such changes to the infrastructure and organization of daily mobility are viewed as key to aligning climate and other sustainable development goals. As travel distances decrease and people make increasing use of NMT and PT instead of cars, citizens will benefit from less congested cities, reduced travel times, the lower costs of NMT and PT, improved road safety, and more open spaces in urban areas, which could be repurposed into green areas to help adapt to climate change…

Figure 7. Passenger mobility per capita (pkm/cap)



CASE STUDY

Examples of end-use electrification

To meet net zero targets, households, companies and public authorities must electrify their remaining energy devices and uses:

- In Argentina, space heating, water heating and cooking in residential buildings represented respectively 43%, 23% and 11% of national household energy consumption in 2018 and were mostly using natural gas. Achieving net zero in the DDS would necessitate a significant shift from natural gas systems to heat pumps, electric or solar water heaters, or electric cooking devices. However, according to Fundación Bariloche, the successful penetration of these technologies will require major economic and financial barriers to be surmounted (Bouille et al., 2021).[19] In the United States, federal tax credits and rebates for appliance efficiency and electrification, enhanced state-level energy efficiency standards, and the implementation of zero-emission appliance standards and zero-emission construction standards can increase building electrification while decreasing overall energy demand.
- For industrial energy uses, in South Africa for example, many processes would need to transition to electricity to meet net zero. Electricity, either directly or indirectly through heat pumps, will be utilized more in industry for processes requiring heat production. In addition, for specific niche applications, hydrogen produced via electrolysis could be used in processes requiring high temperatures, or as a chemical feedstock for some industries like iron and steel, as well as chemicals. Shifting industrial energy uses is a key challenge primarily from a financial perspective rather than a technical one.
- In the transportation sector, in the United States for example, there is a potential to substantially increase electric car and truck sales through a combination of extended federal tax credits for EVs, enhanced state-level EV sales targets and incentives, and corresponding investments in EV infrastructures.

19 https://eficienciaenergetica.net.ar/img_publicaciones/09011503_PropuestaPlaNEEAr.pdf

Long-term transformations in national pathways to net zero

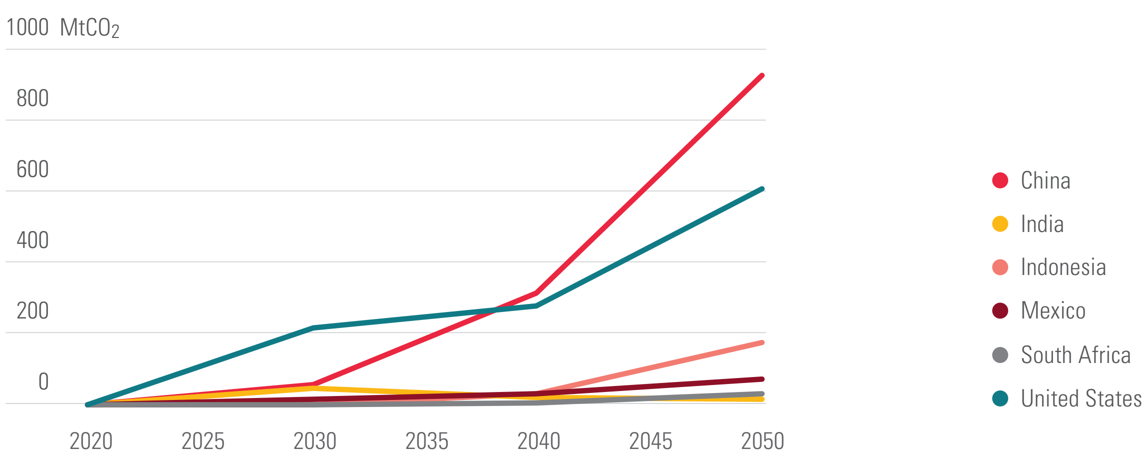
CARBON CAPTURE AND STORAGE

Due to constraints on its potential and challenges affecting the deployment timelines, Carbon Capture and Storage (CCS) will make a limited contribution to cumulative emission reductions by 2050 across all national pathways to net zero. In some countries, it may be able to serve as a supplementary mitigation strategy around mid century to achieve carbon neutrality.

When examined at the country level, it becomes clear that several barriers limit the true potential of Carbon Capture and Storage (CCS). These constraints include geological factors, such as limits to effective national storage capacities or leakage risks related to uncertainties about long-term storage stability; technical factors, such as the energy penalties associated with large-scale sequestration and water use in absorption systems at power plants; spatial characteristics, including the effective localization of emission sources and storage capacity, which can create transport challenges, necessitate significant infrastructure, and lead to negative externalities; and economic considerations, such as the investment costs of capital-intensive infrastructure needed to transport and store carbon, as well as the operational cost resulting from energy penalties. A country-driven assessment of these constraints showed that several of the countries studied identified national pathways to net zero without any reliance on CCS, such as Brazil, Argentina and Nigeria, or assign it a very limited role as is the case for South Africa.

Furthermore even in countries where constraints would not prevent substantial deployment of CCS, its effective role until 2050 is limited by obstacles that affect the timing of its deployment. As of today, there are very few cost-competitive CCS facilities in operation and they are dedicated to specific uses (e.g. natural gas processing and bioethanol production). The development of commercially viable and mature large-scale applications for the power sector and energy-intensive industries would require significant technical progress through research and development, including prototypes and pilot projects. It would also require massive investment to build the infrastructure needed to capture, transport (potentially internationally, especially as large volumes of carbon are likely to be transported, creating a demand for capital-intensive port installations) and store carbon. These innovations and infrastructure processes are characterized by considerable inertia, which means that, even if CCS is deployed, this CCS deployment will be gradual. This temporal constraint means that, even in countries that envisage the potential for CCS technology, it can only be implemented in most countries after 2040 and would not start to play a significant role until around mid century (**Figure 8**). Even in China and the US, which have an earlier deployment of CCS capacities, it mitigates only 22% and 27% of CO_2 emissions from energy and industry by 2050, respectively. Moreover, CCS plays an even smaller role in earlier periods, with only 6% and 13% from energy and industry, respectively, in 2040. CCS is therefore an additional mitigation option to reach carbon neutrality by mid century, complementing other solutions that provide more substantial emission reductions, such as LULUCF (see message 1.3).

Figure 8. Annual CO_2 captured and stored ($MtCO_2$)



Given the constraints and challenges discussed above, CCS can play this role around mid century only if targeted actions are taken to proactively promote it throughout the period. This is, for example, the underlying assumption behind CCS deployment in the US pathway to net zero (see section Enabling long-term emission reductions - Case study US). In other countries, CCS has an even more limited role or is concentrated on very specific uses, such as in South Africa and Mexico, where CCS targets clearly defined industrial emissions (Case study - CCS in Industry). In some countries, the need to integrate CCS with CO_2 utilization pathways has been highlighted as critical for the long-term (cf. Mexico).
This analysis highlights the systemic consequences of the limits and delays in CCS deployment on mitigation strategies across different timeframes, as well as its indirect feedback effect on the overall role of CCS in national pathways to net zero. These constraints necessitate significant efforts to reduce emissions through other mitigation actions in the first decades, particularly by accelerating the reduction of fossil fuel use (cf. message 1.2). This in turn leads to a diminished role for CCS when it becomes available, around mid century.
As a result, CCS could play only a very limited role in reducing cumulative emissions up to 2050 within national pathways to net zero (**Figure 9**).

CASE STUDIES

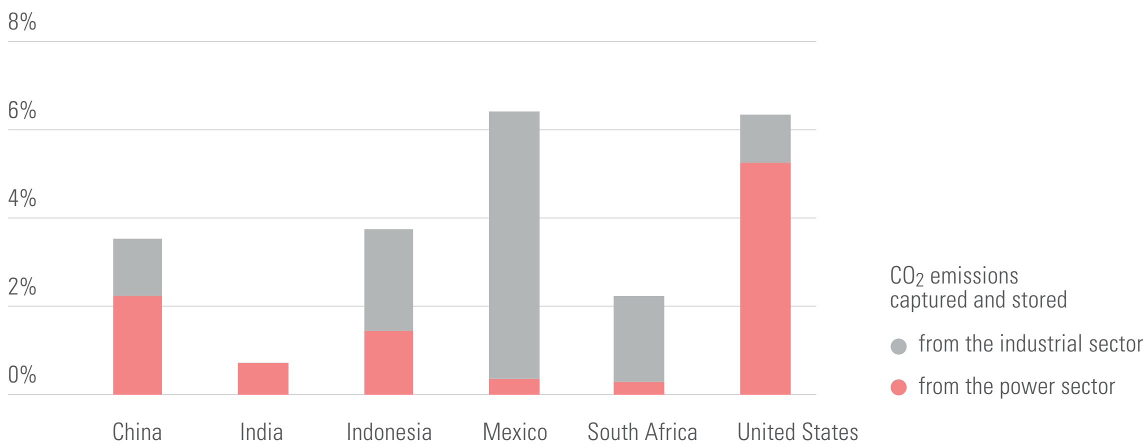
CCS in industry

South Africa

South Africa's underground storage capacity is primarily located offshore, at least 600km from the regions with the highest CO_2 emissions activity, namely the central and eastern provinces of Gauteng and Mpumalanga. The assessment of the capacities of potential geological storage formations, their injectivity, the localization of CO_2 sources and of all necessary infrastructures, along with the related total cost estimates, all derive from World Bank (2017)[20].
Based on these cost estimates, the University of Cape Town showed that CCS will only be necessary for specific industrial uses and processes that are difficult to decarbonize. CCS will be deployed from 2040 and will increase by 2050, with the cement industry needing approximately 15Mt of CO_2 capture, ferroalloys and iron and steel requiring around 9Mt of CO_2 capture, and gas power plants needing around 5Mt of CO_2 storage by 2050. CCS capacities can also be considered, albeit to a very limited extent, for gas power plants that continue to operate at a minimum level due to the intermittency of renewable energy production.

20 https://documents1.worldbank.org/curated/en/247631518158856551/pdf/123200-JRN-PUBLIC-World-Bank-CCS-Program.pdf

Figure 9. Share of CO_2 emissions captured and stored over total 2020-50 cumulated energy & industrial CO_2 emissions



Mexico

Mexico's decarbonization scenario plans to roll out Carbon Capture, Utilization and Storage (CCUS) over the 2030-2050 timescale, primarily targeting emissions from the cement industry, which are expected to grow alongside continued economic development. By 2050, it is predicted that 71 Mt of CO_2 will be captured, 90% of which originating from the industrial sector.

Although the current status of CCUS technologies – both post-combustion and from chemical processes – require further development to achieve widespread availability and affordability, the production of clinker in cement manufacture produces a high-purity CO_2 stream, making its capture technically easier and more cost-effective than post-combustion CCUS, which is often considered for applications such as power generation.

Prioritizing CCUS for the cement industry within Mexico's industrial policy can help drive a faster and more effective adoption of CCUS compared to alternative approaches. Furthermore, Mexico has sufficient renewable resources to transition its power generation away from fossil fuels, making this the primary strategy for electricity decarbonization.

CCUS should be feasible in Mexico as soon as the technology becomes competitive and reliable. The cement industry can provide predictable volumes of easy-to-capture CO_2, while depleted oil fields can provide reliable geological storage. Existing pipelines may facilitate transport, and potential applications could include enhanced oil recovery in the short to medium term, as well as the production of synthetic hydrocarbons in the medium to long-term.

Pursuing synthetic hydrocarbon production can provide decarbonized fuels for aviation and freight, and it should be developed in conjunction with a green hydrogen strategy to ensure that the whole value chain for these fuels remains low-carbon. This highlights the clear synergies in developing CCUS and green hydrogen simultaneously. Achieving these goals will require the development of carbon-focused chemical industries, which should be established urgently to create and pilot practical options, enabling technologies to mature and be rolled out at scale in time to facilitate deep decarbonization by 2050 (as discussed in section 2.1).

Long-term transformations in national pathways to net zero

LAND-USE SECTOR

The land use sector is instrumental in national pathways to net zero, serving as a key provider of carbon sinks up until 2025 and beyond. Country-specific approaches are needed to ensure that mitigation compatible with the sector's other core functions.

The land use, land-use change and forestry (LULUCF) sector has an impact on the carbon fluxes between the atmosphere and terrestrial carbon pools, including biomass and soils. The sector's role in national pathways to net zero varies by country, depending on their starting points and potential (**Figure 10**). Some countries, including Brazil, Indonesia, India, and Nigeria focus on reducing the sector's net CO_2 emissions, while others, such as Mexico, South Africa, China and the US, maintain a relatively stable level of negative emissions. These aggregate results combine efforts to preserve existing carbon sinks by for instance halting deforestation, peat fires and land degradation, as observed in Brazil or Indonesia; and action to increase carbon sinks, for instance by afforestation/reforestation and increased adoption of agroforestry, such as in India. The below case studies further explore the actions taken in Brazil, India and Indonesia in greater detail.

However, beyond these differences, all national pathways to net zero include net negative CO_2 emissions in 2050 for the land use sector. Indeed, this sector is unique in its capacity to generate negative emissions without additional technologies, for instance through reforestation/afforestation and improved management of existing forests. Consequently, it serves as a crucial source of the negative emissions needed to compensate for hard-to-abate CO_2 emissions from the energy and industrial sectors and non-CO_2 emissions from agriculture.

The capacity of the LULUCF sector to act as a carbon sink in the coming decades is however uncertain. Climate change increases the risks for natural disturbances to terrestrial ecosystems, such as fires and droughts, which cause emissions of CO_2 from land-based carbon sinks. This supports diversified mitigation strategies that both drastically reduce CO_2 emissions in other sectors, and increase negative emissions in LULUCF.

The importance of the land use sector in national pathways to net zero can also be measured in its impact on cumulative CO_2 emissions. Despite significant variation across countries, the LULUCF sector is a net absorber of CO_2 emissions when considering its cumulative emissions and absorptions from 2020 to 2050 in all of the countries studied (as indicated by a positive percentage in **Figure 11**). However, the different national starting points and pathways lead to notable differences in the share of cumulative CO_2 emissions captured by LULUCF. In Brazil, the magnitude of emission reductions and annual CO_2 sequestration means that LULUCF captures nearly 80% of the country's total CO_2 emissions released between 2020 and 2050. This highlights the country's significant potential for negative emissions, which is being maximized in its national pathway to net zero, making action in the sector a priority mitigation strategy (see section 2.3). In Mexico, stable and relatively significant negative emissions from LULUCF between 2020 and 2050, combined

Figure 10. CO_2 emissions from LULUCF in DDS ($MtCO_2$)

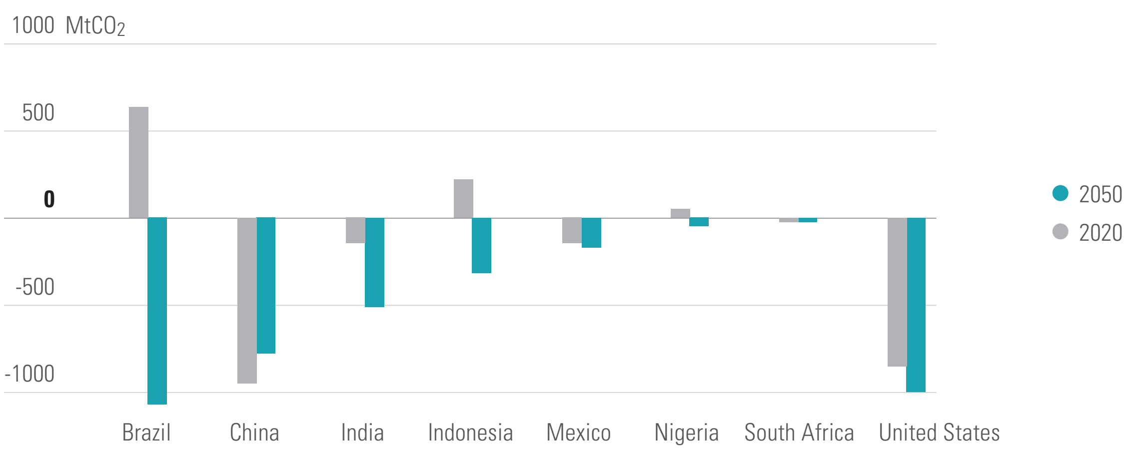
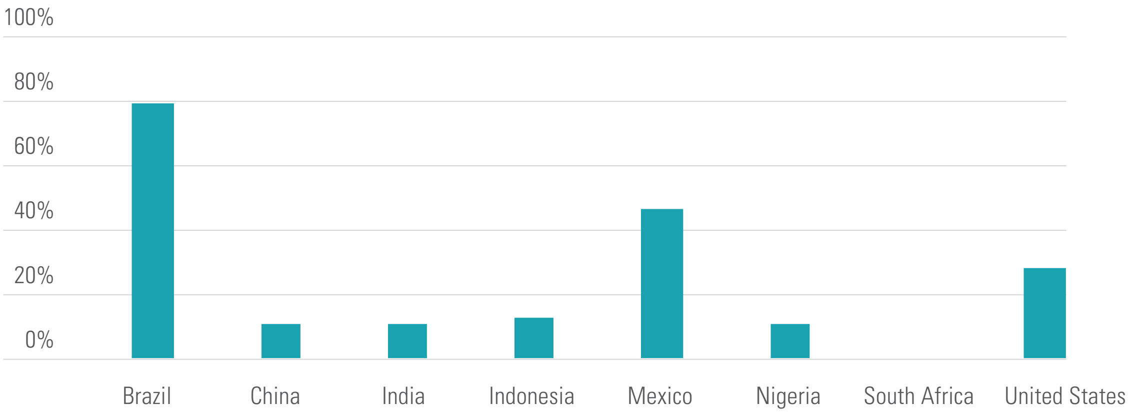


Figure 11. Share of cumulative CO_2 emissions (2020-2050) from all other sectors captured by LULUCF

(except LULUCF)



Note: the LULUCF sector in Argentina has not been analysed in detail, and Argentina is therefore not included in this graph.

with a robust mitigation strategy, are projected to capture about 45% of the country's CO_2 emissions released over the period. In contrast, India captures only 11% of its cumulative emissions from LULUCF, despite notable reductions in net emissions between 2020 and 2050. This is due to the fact that carbon neutrality will be reached after 2050, and CO_2 emissions from other sectors will remain significant until 2050. Similarly, in Indonesia, LULUCF absorbs only 12% of cumulative CO_2 emissions from other sectors between 2020 and 2050. This reflects both that Indonesia aims for carbon neutrality in 2060 and have significant CO_2 emissions in 2050, and that the LULUCF sector is a net emitter in 2020, which limits cumulative sequestration despite rapid net emission reductions.

The analysis of national pathways to net zero also highlights the need for country-specific approaches for transforming the LULUCF sector and the broader land use system, including agriculture. LULUCF's significant mitigation potential can only be realized if the sector also contributes to food security, rural employment, and resilient and biodiverse ecosystems, and other key functions of the sector. Given the locally specific character of eco-climatic and socio-economic systems, solutions that align these functions must be context specific. Examples of such country specific solutions include the restoration of degraded grasslands to drastically reduce deforestation without reducing agricultural production in Brazil, and increasing the support to farmers for adopting agroforestry to improve the quality of often degraded agricultural soils and providing farmers with alternative sources of revenues in India. The following case studies on Brazil, India and Indonesia illustrate how context-specific solutions can effectively provide the multiple functions that the land use system must play.

CASE STUDY

Context-specific solutions to balance increased absorption capacity with other core functions in the land use sector in Brazil, India and Indonesia

Brazil

In Brazil, the LULUCF sector will transition from emitting over 0.6 $GtCO_2$ in 2020 to absorbing more than 1 $GtCO_2$ in 2050. Halting deforestation is the single most important measure to reduce emissions and preserve climate-resilient, biodiverse ecosystems.

Achieving this level of mitigation requires balancing environmental conservation with the country's economic reliance on agricultural production. Agriculture, particularly extensive cattle rearing and soy production, is the primary driver of deforestation. However, the sector is also crucial for the country's economy, contributing significantly to the balance of payments with important export revenues. To tackle this issue, Brazil is adopting strategies that align climate mitigation with economic resilience, aiming to both reduce deforestation and sustain agricultural productivity. One key strategy is the restoration of extensive degraded pasturelands. By rehabilitating these areas for agricultural expansion, Brazil can avoid deforestation while ensuring continued growth in food production and agri-business exports. This approach facilitates sustainable intensification, where advanced agricultural practices—such as integrated crop-livestock-forest systems (ICLFS)—enhance productivity per hectare, reducing the pressure to clear new areas of native forest.

Additionally, policies tailored to the national context—such as the enforcement of the Forest Code and the promotion of sustainable agriculture—are fundamental to ensuring that mitigation efforts do not compromise food security or economic growth. By incorporating local knowledge and aligning policy with the specific needs of different regions (such as the Amazon and Cerrado biomes), Brazil can create solutions that not only curb emissions but also support the livelihoods of rural communities, maintain biodiversity, and promote climate resilience.

This balance between climate action and land use is essential to ensure that Brazil meets its climate commitments while continuing to serve as a global leader in agricultural production.

India

In India, the annual net CO_2 absorption by the LULUCF sector is projected to increase from 112 to 518 $MtCO_2$ between 2020 and 2050. A key driver of this trend is the increased adoption of agroforestry on croplands. However, the large number of smallholders in India means there are challenges to accessing efficient farming practices and markets, which contributes to persistently low incomes for the majority of Indian farmers. Furthermore, Indian farmland faces significant challenges from soil degradation, which threatens to further reduce harvests and farmer revenues if not addressed. The agroforestry approach offers multiple benefits. In addition to its contribution to mitigation, it provides alternative sources of income for farmers, reducing their reliance on single crops. It also enhances soil structure and water retention in croplands, leading to improved resilience to the unpredictable impacts of climate-change related natural events.

Indonesia

In Indonesia, the LULUCF sector is projected to transition from emitting over 220 $MtCO_2$ in 2020 to sequestering more than 330 $MtCO_2$ by 2050. This significant shift from net emissions to a net annual carbon sink is primarily driven by reductions in deforestation and forest degradation, along with the restoration of degraded peatlands and mangroves and the expansion of forested land. To align the conservation of natural and semi-natural ecosystems with rural livelihoods, Indonesia is exploring sustainable forest and agricultural production systems that minimize damage to peatlands and forests, while also promoting incentives for ecosystem service benefits through market and non-market mechanisms.

Long-term transformations in national pathways to net zero

SOURCES OF NON-CO_2 EMISSIONS

Measures designed to address CO_2 emissions are not sufficient to reduce non-CO_2 emissions from agriculture in national pathways to net zero. Targeted actions on non-CO_2 gases require a country-driven approach to the transformation of the agriculture sector

In national pathways to net zero, non-CO_2 emissions from the energy sector will significantly decrease in almost all countries (**Figure 12**). These reductions result from actions that drive the energy transition away from fossil fuels, primarily to reduce CO_2 emissions. Non-CO_2 emissions in the energy sector largely originate from coal mining and oil and gas extraction. Therefore, as fossil fuel production decreases, methane (CH_4) and nitrous oxide (N_2O) emissions from the energy sector will also decrease. In addition, some countries have implemented specific measures to further reduce non-CO_2 emissions from coal mining and oil and gas extraction. For example, in China, the implementation of enhanced methane recovery technologies, stricter regulations, and policies that prioritize the early closure of gas-rich coal mines are important measures to reduce non-CO_2 emissions from the energy sector (see the following case study on the reduction of non-CO_2 emissions from energy and agriculture).

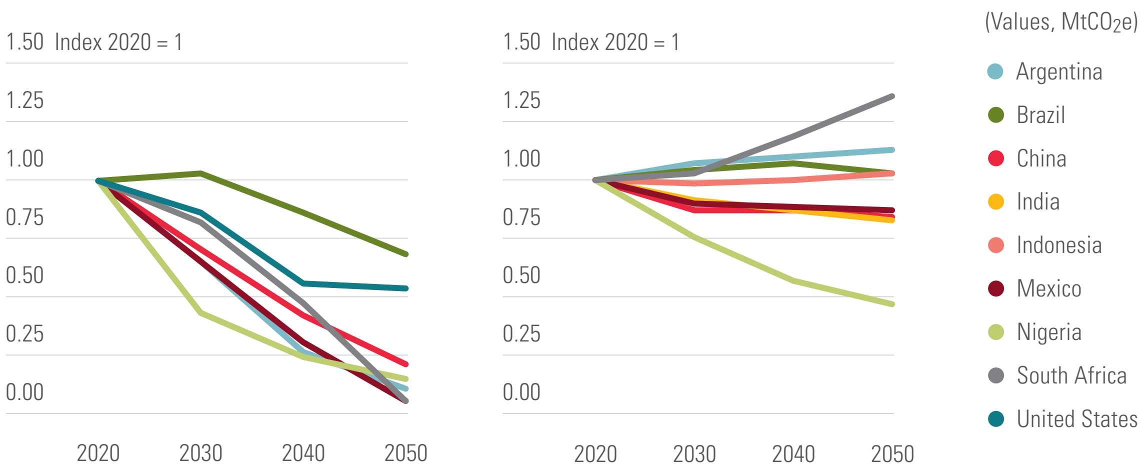
In contrast, CH_4 and N_2O emissions from agriculture, which accounted for between 7% and 30% of total GHG emissions in 2020 in the countries studied, show a very different pattern by 2050. Although trends vary by country, it is noteworthy that no country significantly reduces non-CO_2 emissions from agriculture: in some countries these emissions increase, while in others they decrease only marginally (**Figure 12**). This trend can be attributed to the fact that the sources of these emissions differ from CO_2 sources and are therefore not addressed by measures targeting CO_2 emissions, which constitute the core of the analysis presented in this study. The main sources of methane include enteric fermentation from ruminant digestion and manure management from livestock, as well as rice cultivation, while the main sources of nitrous oxide include livestock manure and fertilizer use.

CASE STUDY – CHINA

The transition away from fossil fuels is expected to significantly reduce methane and nitrous oxide emissions from the energy sector, but non-CO_2 emissions from agriculture require targeted mitigation action

The coal sector is responsible for approximately 85% of China's energy-related methane emissions and 45% of its anthropogenic methane emissions. Achieving carbon neutrality will require a peak in coal consumption and production followed by a rapid decline, which is expected to reduce energy methane emissions by about 90% by 2060. However, phasing out coal will result in the closure of more than 3,000 coal mines, and abandoned coal mines represent a methane emission source that is not fully accounted for in current inventories. To address this, implementing enhanced methane recovery technologies, stricter regula-

Figure 12. Indexed Non-CO_2 emissions from energy and agriculture



tions, and policies that prioritize the early closure of gas-rich coal mines will be critical for effectively controlling and mitigating methane emissions from these abandoned mines. China's case highlights the dual impact of energy transition policies: while they offer substantial benefits in reducing methane emissions, they also cause unintended consequences—such as increased methane emissions from abandoned coal mines—and so must be carefully managed. Thus, both carbon dioxide and other GHG emissions must be addressed holistically to maintain the environmental integrity of national policies.

The agricultural sector remains one of the most challenging sectors to decarbonize due to a lack of advanced mitigation technologies, limited capacity, and the difficulty of accurately measuring emission reductions cost effectively—especially in a sector dominated by small-scale farmers. Even in GHG neutrality scenarios, over 80% of residual emissions are expected to originate from agriculture, primarily as methane and nitrous oxide. While improving water management in rice cultivation and optimizing nutrient management in animal husbandry theoretically offer significant mitigation potential, realizing these reductions is challenging due to the need to modify entrenched practices among millions of small-scale farmers. As a result, effective policy incentives and innovative solutions are essential for turning these theoretical mitigation potentials into reality.

To demonstrate how non-CO_2 in the energy sector are reduced by actions targeting CO_2 emissions, a scenario that assumes that no actions specifically target non- CO_2 emissions are pursued results in an 85% reduction in non-CO_2 emissions from energy between 2020 and 2070. In comparison, a scenario that aims to mitigate all GHGs leads to a 94% reduction in non-CO_2 emissions from energy. The same is not true for agriculture, however. The scenario targeting CO_2 emissions achieves only an 8% reduction of non-CO_2 emissions from agriculture by 2070, while the scenario targeting all GHGs achieves a 21% reduction in non-CO_2 emissions from this sector. The still limited reduction of non-CO_2 from agriculture in the latter scenario illustrates the challenges inherent in reducing emissions from agriculture.

Some countries, however, make assumptions about measures that specifically target the reduction of non-CO_2 emissions from agriculture, primarily by reducing the emission intensity of agricultural output. For instance, Brazil assumes that the carcass weight of cattle will increase by 30% by 2050, making beef production less emission-intensive, and that fertilizer application will decrease from the current average of 60 kg/ha. The case study on Nigeria illustrates how non-CO_2 emissions in agriculture are projected to fall from 75 MtCO_2eq/yr in 2020 to 36 MtCO_2eq/yr in 2050.

CASE STUDY – NIGERIA

Enabling Strategies to reduce non-CO_2 emissions from agriculture

The agriculture sector accounted for nearly 38% of total employment in Nigeria in 2022.[21]

Specific agricultural activities contributing to GHG emissions include enteric fermentation from domestic livestock, livestock manure management, rice cultivation, agricultural soil management, field burning of agricultural residues, as well as liming, urea fertilization, and on-farm energy use. Enteric fermentation accounts for nearly half of these emissions alone.

The DDS indicates that Nigeria is projected to reduce non-CO_2 emissions from 75 MtCO_2eq in 2020 to 36 MtCO_2eq in 2050.[22] This 52% reduction is achieved through a combination of strategies that simultaneously target the achievement of key Sustainable Development Goals (SDGs), including poverty eradication, zero hunger, improved health and well-being, and the promotion of decent work and economic growth. The key strategies are:

Precision Agriculture and Urban Farming

Prioritize the use of technology and data-driven approaches to optimize resource use, reduce waste, and improve the efficiency of agricultural practices in rural and urban environments.

21 https://www.statista.com/statistics/1288871/agriculture-sector-share-in-employment-in-nigeria

22 Nigeria's Deep Decarbonization Pathways Report (2024): https://cccd.funai.edu.ng/nigeria-deep-decarbonization-pathways-ddp-for-nigerias-low-emission-development-up-to-2060-report/

Improved Livestock Management
Implement targeted and stringent policies promoting rotational grazing and other sustainable livestock management practices to reduce emissions from enteric fermentation and manure.
Integrated Water Resource Management
Adopt practices that improve water use efficiency, reduce erosion, and protect water quality in agricultural and forestry activities.
Supportive Policies and Incentives
Establish policies that incentivize climate-smart practices, including financial incentives, subsidies, and regulations that promote sustainable land use.
Knowledge Transfer and Capacity Building
Provide training and capacity-building programmes to farmers, foresters, and other stakeholders to enhance their understanding and adoption of climate-smart practices.

Furthermore, the technical mitigation potential in agriculture from actions that improve the GHG efficiency of agricultural output is limited, indicating that there are upper limits to the emission reductions achievable while ensuring global food security. For instance, emissions from enteric fermentation from livestock can be reduced by approximately 30% if cattle diets are modified but significantly deeper reductions of emissions from this source are not possible with today's knowledge.[23] A systemic transformation of agriculture, including shifts in demand, production methods, and increased diversity of crops and livestock provides a possible solution for achieving deeper reductions of non-CO_2 emissions from agriculture. However, there are no options that exist to reduce agricultural non-CO_2 emissions to near zero. This suggests that negative emissions from LULUCF are needed to compensate for hard-to-abate emissions in agriculture. Furthermore, many countries are hesitant to pursue transformative actions in agriculture due to concerns of negatively impacting rural livelihoods, food security, or export revenues from the agri-business sector. There is a need for further guidance on how to align reductions in non-CO_2 emissions from agriculture with positive outcomes for rural livelihoods and food security (Case study on China for an example).

Indeed, agriculture, and particularly primary agricultural production, is the predominant employer in many low-income countries, providing employment to 1.23 billion people, and further contributes to the livelihoods of 3.83 billion people worldwide.[24] Furthermore, the sector plays a vital role in ensuring global food security and developing food value chains that are resilient to climate change. A comprehensive strategy for transforming the sector that clearly defines these objectives is essential to fully integrate the agricultural sector into national pathways to net zero. The recent UAE Declaration on Sustainable Agriculture, Resilient Food Systems and Climate Action demonstrates the commitment of 160 States to move in this direction. This intent must now be translated into long-term strategies and sectoral policies to achieve tangible results.

23 Searchinger, T. (2019). Creating a sustainable food future: A menu of solutions to feed nearly 10 billion people by 2050. World Resource Institute, Washington DC. Available online: https://research.wri.org/wrr-food

24 Davis, B., Mane, E., Gurbuzer, L.Y., Caivano, G., Piedrahita, N., Schneider, K., Azhar, N., Benali, M., Chaudhary, N., Rivera, R., Ambikapathi, R. and Winters, P. 2023. Estimating global and country-level employment in agrifood systems. FAO Statistics Working Paper Series, No. 23-34. Rome, FAO. https://doi.org/10.4060/cc4337en

Immediate actions in national pathways to net zero

Immediate actions in national pathways to net zero

ENABLING LONG-TERM EMISSION REDUCTIONS

National pathways to net zero involve short-term actions across infrastructure and technology, governance and institutions, and lifestyle and behaviour changes. While these short-term actions may not deliver immediate emission reductions, they are essential for laying the foundation for the long-term changes needed in each country

Rapid emission reductions are necessary to put countries on track with carbon neutrality (Section - Triggering short-term emission reductions). However, an excessive focus on immediate emission reductions runs the risk of overlooking an important category of mitigation actions, i.e. those which, while not delivering immediate emission reductions, are nevertheless essential to drive structural changes in infrastructure and organizations, and to achieve deeper emission reductions by mid century, as highlighted in Section - Use of fossil fuels

The challenge with these structural changes is that they are often characterized by significant inertia and resistance to change. For public and private decision-makers, this presents the challenge of a time lag between their actions on the drivers and their tangible effect on emissions. Due to this inertia, it is crucial to consider short-term actions today in the perspective of their longer-term negative or positive impacts on emissions. For example, short-term actions that may create new carbon lock-ins in the future (negative impacts) should be avoided. Conversely, short-term actions that address the various sources of inertia associated with these structural changes and offer potential longer-term emission reductions (positive impacts) should be prioritized.

According to the diversity of national pathways to net zero analysed, the results highlight that all sectors are affected by these structural changes and that the sources of inertia are sector and country-specific. Delving deeper, we identified at least three main sources of inertia: 1) infrastructure and technologies (Case studies - China, Senegal and the United States), 2) governance and institutions (Case study - Nigeria), and 3) lifestyles and behaviours (Case study - India). The following examples illustrate structural changes in different sectors and characterize country-specific actions that address certain sources of inertia. These actions should be better anticipated and implemented in the short term by decision-makers, because these sources of inertia are particularly rooted in the specificities of national contexts.

In the power sector, for example, country analyses show that fossil fuel-based power generation capacities must be drastically reduced by 2050, while renewable energy capacities should be increased. First, all countries recognize the need for long-term investments in adequate infrastructure for the transmission and distribution of power, tailored to the specificities of renewable energy sources (different geographical distribution, intermittencies…) and for the new uses of power systems (distributed generation, power storage, electric vehicles…). These investments should be planned now to facilitate the rapid expansion of renewables in the next decades. Additionally, such long-term transformations will largely depend on upfront investment decisions in power production infrastructure and technologies (1), which have long lifetimes and pose risks of carbon lock-in. Depending on country circumstances, some short-term actions should be taken on current power plant investments (Case study - China and Senegal) or on future technological innovations. These innovations will require significant investment in research and development before they can reach commercial viability, as exemplified by CCS technologies (Case study - United States).

In the freight transport sector, for example, country analyses show that a structural shift away from diesel trucks to rail, inland water and coastal transport will contribute to reducing emissions from freight by 2050. First, all countries recognize the importance of actions on infrastructure and technologies (1) to develop railways, inland waterways and coastal shipping logistics and infrastructure to efficiently connect these modes of transport to road transport. Additionally, a number of targeted and country-specific measures have been identified regarding the governance and institutional conditions (2) in the sector, to effectively support the envisaged sectoral changes (Case study - Nigeria).

Finally, for the transition of food and energy systems, country analyses highlight the need to develop demand-side strategies in all sectors aimed at changing lifestyles and behaviours (3) to facilitate the adoption of low-carbon solutions. Such changes will take time and can only develop progressively as they depend on our collective capacity to change social norms and cultural habits (Case study - India).

CASE STUDY – CHINA

Early termination of new coal-fired power plant construction

China's power sector presents a complex paradox. While the country leads the world in renewable energy installations, accounting for 63% of global wind and solar capacity additions, it nevertheless continues to approve new coal power plants. In 2023 alone, China's photovoltaic (PV) installations exceeded the world's total PV additions from 2022, and the country is set to reach its 2030 target of 1,200 GW of wind and PV capacity by 2024, six years ahead of schedule.

However, despite this remarkable progress, over 200 GW of coal power was approved in 2022 alone, highlighting the complex dilemmas China faces in its transition to a low-carbon economy. The rapid growth in electricity demand is outpacing renewable capacity and while the share of renewables in the energy mix is rapidly increasing, the power system lacks sufficient clean and flexible peaking capacity to ensure grid stability. Additionally, coal remains the dominant source of heat for district heating in northern China, where the adoption of cleaner technologies has not yet gained traction.

China's electricity demand grew by 6.7% in 2023, an annual increase equivalent to Germany's total electricity consumption. Despite the installation of roughly 300 GW of new wind and PV capacity in 2023, this expansion alone is insufficient to meet the rising electricity demand. As a result, China has had to approve new coal power projects to bridge the gap. Compounding this challenge, gas-fired power plants account for only about 5% of China's total generation capacity, which leaves coal as the primary source for meeting peak demand as renewable energy penetration increases. Furthermore, over 50% of winter heating in northern China comes from coal-fired cogeneration plants, complicating efforts to phase out coal power in this region.

While the construction of new coal plants may address short-term power and heating needs, these plants are likely to become stranded assets in the long-term, complicating China's energy transition towards carbon neutrality. From an economy-wide perspective, the analysis reveals that the power generation capacities planned under the Current Policy Scenario (CPS) could quadruple the cost of stranded assets. In contrast, freezing the building of new coal power plants as soon as possible could significantly decrease it. Although reducing or halting new coal-fired power construction is possible, China must simultaneously accelerate efforts to meet incremental power supply needs, enhance grid flexibility, and accelerate the development of low-carbon heating solutions, particularly in northern regions.

CASE STUDY – SENEGAL

Moderate gas development combined with renewables to enable universal access to electricity while mitigating long-term carbon lock-ins

In light of significant gas field discoveries, Senegal aims to rely on its resources to achieve universal access to electricity and foster the socio-economic development of its territories, as outlined in the government's "Gas To Power" strategy established in December 2018. This strategy includes plans to convert existing heavy fuel oil and coal-fired thermal power plants into natural gas plants, with an installed capacity of 3 GW, along with more than 800 MW of additional capacity. This energy policy is expected to increase the share of fossil fuels to about 60% of the energy mix by 2030.

However, while gas-fired power plants emit fewer greenhouse gases (GHGs) than oil and coal plants, they still emit a significant amount of GHGs (more than 400 gCO_2/kWh) and will continue to do so over their operational lifespan of around 40 years. Consequently, ENDA-Energie has developed several scenarios for natural gas development to assess the potential short, medium, and long-term impacts on socio-economic and climate goals.

One of their scenarios focuses on extensive gas development, as outlined in the gas sector master plan. While this scenario meets the objective of universal electricity access, it does so in a suboptimal manner. Indeed, this scenario focuses solely on gas sector development, which could hinder the planned expansion of renewable energy as outlined in the renewable energy strategy. Furthermore, this scenario is not compatible with ambitious long-term climate objectives.

Another scenario emphasizes moderate gas development, combined with the growth of renewable energy production capacity. This scenario not only accelerates universal access to electricity but also achieves more ambitious climate goals in the medium and long-term. Gas development is relevant when it is designed to support the electrification of energy uses (transport, cooking, industrial production...), that are necessary in the long-term. In the short term it facilitates the integration of renewable electricity while gradually decreasing to create space for renewable energy sources over time.

Finally, one of the scenarios shows that efforts to improve energy efficiency can also help achieve universal electricity access and meet climate goals by reducing pressure on electricity generation needs.

CASE STUDY – UNITED STATES

Investing in technological innovations related to CCUS

Carbon capture, utilization and storage (CCUS) development has been a focus in the US since the 1970s, primarily through Enhanced Oil Recovery (EOR) and Enhanced Gas Recovery (EGR) techniques, which were developed to access oil and gas from reserves that required CO_2 injection for extraction.

Since then, the government has taken significant steps to advance CCUS development beyond EOR and EGR. In 2009, the American Recovery and Reinvestment Act allocated $3.4 billion in funding for CCS programmes, although not all of these funds were utilized. Between 2011 and 2023, Congress also allocated $5.3 billion (in nominal dollars) for CCS research and development. Additionally, from 2010 to 2019, companies claimed a total of $1 billion in Section 45Q federal tax credits, which provide subsidies per ton of carbon captured.

The future development of CCS in the US will greatly depend on deployment costs, as this will influence the companies' decisions regarding the adoption of such technologies. The availability of pipelines and underground storage capacity for CO_2 will be crucial for the transportation and storage of captured CO_2, which will require investment amounting to several billion dollars.

The US is well-positioned to further develop CCUS due to its energy economy, abundant natural resources, and innovation-driven manufacturing sector. More than half of all operational, commercial, large-scale CCS facilities are located in the US, and due to the enhanced 45Q tax credit, 12 of the 17 new CCS facilities being developed globally are in the US. The country also possesses significant storage potential, estimated at 3,000 metric gigatons of carbon dioxide.

More recently, the Inflation Reduction Act of 2022, established a tax credit to deploy the least-cost CCS technologies (up to $85 per ton of CO_2 captured), while the Bipartisan Infrastructure Law of 2021 provided $2.5 billion for carbon capture demonstration projects from 2022 to 2026.

At the subnational level, several states are now at the forefront of CCS implementation, having established carbon dioxide removal (CDR) targets. For example, California aims for a 40% CCS target in cement production by 2035 and a 15% emission reduction target for CDR by 2045. New York, New Jersey, Massachusetts, Maryland, and Colorado have established similar targets. Texas and Illinois provide tax credits for carbon sequestration, while states like Wyoming and Louisiana have established financial incentive programmes, providing direct financial assistance, tax incentives, state assumption of long-term liability, and mechanisms for utility cost recovery, among other benefits.

CASE STUDY – NIGERIA

Setting new governance and institutional rules to develop rail freight and limit the dependency on road freight

Nigeria's freight transport is dominated by road transport, which represents 99% of goods traffic. This heavy reliance on road transport has led to issues such as traffic congestion, infrastructure degradation, and high emissions. A transition to rail freight offers substantial benefits,[25] but addressing governance and institutional barriers is critical to unlocking these opportunities. Given the typical inertia associated with governance reforms, it is essential to initiate these changes promptly to secure future emission reductions.

First, the central government must play a leading role in the planning and prioritization of rail network routes. A coordinated, national approach would maximize economies of scale and establish vital regional connections, positioning Nigeria as a central player in regional trade partnerships. Centralized planning is essential to avoid a fragmented and inefficient network, which could emerge if regional politics were the primary driver of decision-making. However, collaboration between central and regional governments is vital to address regional security concerns, particularly in the northeast, where threats have hindered the development of an efficient national rail system. Security risks also loom over potential southern coastal lines, making joint efforts indispensable to achieving a comprehensive and reliable rail network.

Second, a new framework law for rail development must be introduced to establish governance structures that attract investment, ensure safety, and promote efficiency. This law should incorporate best-in-class standards to meet international benchmarks, ensuring that Nigeria's rail system is modern, competitive, and capable of supporting national growth. The government could create public-private partnership (PPP) opportunities, opening the rail sector to private and international investors. These partnerships would generate new financing streams and foster competition between Nigerian and foreign actors, driving innovation and growth. However, governance frameworks must include provisions to ensure that private investments contribute to inclusive, sustainable development. Obligations should be established to prioritize the employment of local workers, support local businesses, and mandate skills training to ensure long-term sustainability and capacity for rail infrastructure operations and maintenance. Furthermore, involving national companies in project structures will facilitate technology transfer, allowing for the growth of domestic expertise.

Finally, in terms of governance, a new framework law must emphasize the central state's pivotal role in planning, while also fostering inclusive governance. A new governance structure should establish rules that require consensus-building on large-scale projects, ensuring that all stakeholders, including Nigeria's indigenous peoples, participate in national development. Additionally, this approach should support the deep decarbonization of the transport sector, aligning with Nigeria's long-term environmental goals. Achieving a modal shift from road to rail freight is a crucial part of this transformation, and without immediate action on governance reforms, this shift—and the corresponding reduction in emissions—may be delayed. Governance and institutional reforms often face delays due to political and bureaucratic inertia, but such delays could exacerbate the country's reliance on road transport, leading to prolonged environmental degradation and missed opportunities for decarbonization.

In conclusion, Nigeria's shift towards rail freight is not just a logistical necessity but a critical component of its long-term decarbonization strategy. Governance and institutional reforms are often slow-moving, but addressing them now is essential for unlocking future emission reductions, improving infrastructure, and fostering sustainable, inclusive development. The time to act is now, and central leadership, strong legal frameworks, and inclusive governance will be key to transforming Nigeria's freight transport system and securing its environmental and economic future.

25 Akujor C.E. et al., 2022; Emodi N.V. et al., 2022

CASE STUDY – INDIA

Embracing Lifestyle For Environment (LiFE) is a necessary global movement to achieve net zero

For the deep decarbonization in India, balancing global climate targets with domestic development goals in the latter half of this century presents significant challenges.

Development and energy security will remain top priorities for India. Key targets of the country's DDS pathway include eradicating poverty and hunger, ensuring housing for all, and boosting employment. With a growing urban population and rising infrastructure demands by 2030, household energy needs are set to rise, thereby requiring industrial production to meet this demand. Rapid urbanization and rising income levels will drive the demand for an improved quality of life. Cumulative investment estimates based on numerous sources range from $6 to $10 trillion between 2015 and 2030. As a result, electricity demand across sectors (industry, transport, buildings) is projected to increase significantly in deep decarbonization scenarios.

Transitioning to a low-emission energy supply is essential and can be achieved in two steps. In the medium term, the simultaneous development of gas and renewable electricity will lead to an increase in emissions in the DDS pathway and may create lock-ins due to reliance on gas infrastructure for several decades. However, in the long-term, India aims to transition entirely to zero-emission electricity. To support this goal, the country plans to invest after 2030 in stationary and mobile battery storage to accommodate the increase in renewable power capacity and generation.

Achieving India's development goals will inevitably increase energy demand, placing significant pressure on the decarbonization of the power supply. To address this, demand-side policies are needed to foster structural changes in lifestyles and behaviours related to energy use. LiFE[26] was introduced by Prime Minister Narendra Modi at COP26 in Glasgow on 1 November 2021 as a mass movement for "mindful and deliberate utilization, instead of mindless and destructive consumption" to protect and preserve the environment. It aims to encourage individuals and communities to adopt lifestyles that are in harmony with nature. India is the first country to include LiFE in its NDC. Lifestyle changes encompass shifts in demand, supply, and policy across end-use sectors which include about 30 actionable items in the energy and Agriculture, Forestry, and Other Land Use (AFOLU) sectors. In the DDS, these changes will impact emission reductions after 2035-2040, as it will take at least a decade for the policies to be scaled up and be implemented nationwide. These measures also align with the Sustainable Development Goals.

The following two examples illustrate lifestyle and behavioural changes that can be achieved by nudging individuals, communities and institutions to adopt simple, environment-friendly actions:

- sustainable food systems can be adopted by prioritizing locally available and seasonal foods, incorporating millets into diets through initiatives like those operated by Anganwadi[27] centres, midday meals, and public distribution schemes for food grains; or even creating kitchen gardens and terrace gardens at homes, schools or offices.
- energy conservation can be achieved by using public transport and carpooling wherever possible, setting air conditioning temperatures only 5 to 7 degrees below the outside temperature, and limiting domestic energy consumption.

26 https://www.niti.gov.in/sites/default/files/2022-11/Mission_LiFE_Brochure.pdf

27 Anganwadi is a type of rural child care centre in India. It was started by the Indian government in 1975. A typical Anganwadi centre provides basic health care in a village (contraception, nutrition education and pre-school activities).

Immediate actions in national pathways to net zero

TRIGGERING SHORT-TERM EMISSION REDUCTIONS

Immediate CO_2 emission reductions are primarily achieved through improvements in power generation, passenger transport and land use in national pathways to net zero. Technical solutions already exist in these sectors and the policies needed to accelerate their deployment are often well identified in each country.

Immediate emission reductions are crucial for putting each country on track with the long-term net zero objective. It is essential that these immediate emission reductions preserve the capacity for deeper, long-term reductions and avoid the creation of new carbon lock-ins (cf. message 2.1). National pathways to net zero highlight three sectors with the greatest potential for immediate emission reductions consistent with the long-term goals: power generation, passenger transport and land use.

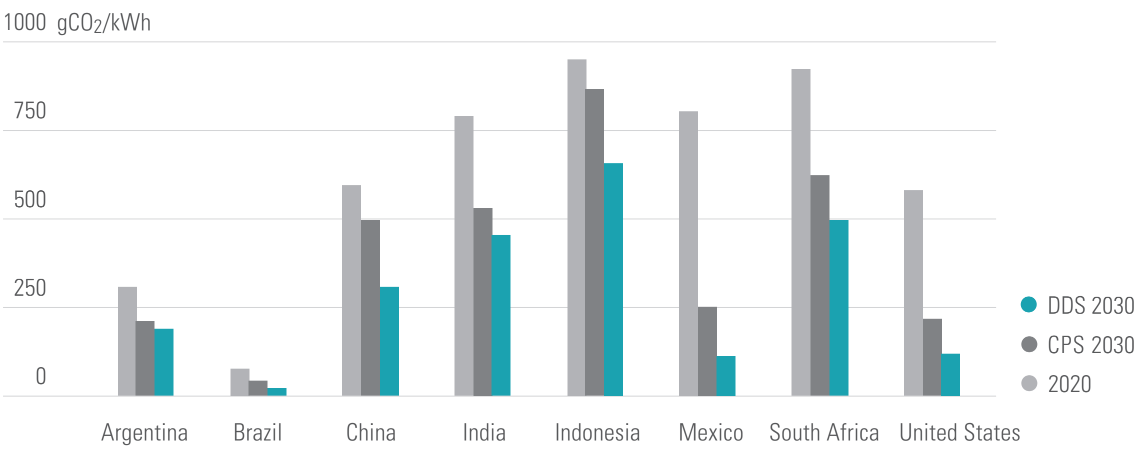
These three sectors share the characteristic that technical solutions for CO_2 emission reductions are readily available and commercially viable. As a result, achieving immediate emission reductions relies on the establishment of an adequate enabling environment to accelerate the diffusion of these solutions.

POWER GENERATION

The rapid decarbonization of power generation is critical in national pathways to net zero, because it is the highest energy-related emitting sector in most countries (except Brazil, which already has a very low-carbon electricity system based on hydroelectric power) and, most importantly, because the availability of decarbonized electricity in the medium term is essential for the decarbonization of many end-uses, for which electrification is the best route (see message 1.2). Electricity produced from renewable energy sources, such as hydro, solar, wind or biomass, is cheaper than fossil fuel options in most countries, meaning that economic costs are not a fundamental obstacle to the diffusion of these low-carbon alternatives[28]. However, when examining current trends at the country level, as analyzed in CPS scenarios, the projected adoption of these technologies in the near future is often not as large as required in national pathways to net zero. **Figure 13** shows that, although the carbon intensity of electricity decreases by 2030 in all countries under current trends, national pathways to net zero indicate a significant acceleration of this decrease by the same date.

28 Clarke, L., Y.-M. Wei, A. De La Vega Navarro, A. Garg, A.N. Hahmann, S. Khennas, I.M.L. Azevedo, A. Löschel, A.K. Singh, L. Steg, G. Strbac, K. Wada, 2022: Energy Systems. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.008.

Figure 13. Carbon intensity of electricity (gCO_2/kWh)



This gap can be attributed to specific constraints affecting the diffusion of low-carbon options, which are proactively addressed in national pathways to net zero through targeted and country-specific sectoral policies. Among these, the organization of the power market plays a particularly important role. Indeed, the power market has been historically structured around thermal power plants and fossil fuel usage, so that the penetration of alternative energy sources at scale requires a profound change in the management and distribution of power generation.

Country analyses illustrate that the accelerated adoption of low-carbon energy sources in electricity production may depend significantly on targeted measures that adjust market rules. These measures aim, for example, to incentivize public and private investments, to facilitate the participation of private companies in the power market, and to create clear market signals in favour of low-carbon options. Depending on specific country circumstances, this can be achieved by allowing independent private participation or joint ventures, through public auctions, or through improved production quotas and associated penalties (Case study - Mexico and Argentina)

CASE STUDY – MEXICO

Public auctions and private participation to accelerate and lower power sector costs

In 2013, Mexico enacted an energy reform to open the electricity generation market to private entities, while maintaining state control over energy planning, grid operation, development of transmission and infrastructure, and electricity distribution. Previously, these functions were exclusively carried out by the two state-owned utilities: CFE and PEMEX. After 2013, private electricity suppliers were then allowed to sell their energy to a wholesale market from which distributors could sell electricity to final users. Private generators could operate independently or in public-private partnerships.

During the period from 2015 to 2018, Mexico enacted public auctions as a mechanism to allow private electricity generators to install renewable production capacities and exploit renewable resources in competitive long-term energy supply contracts. This boosted private investment in the sector during those years, while reducing the production costs of electricity and facilitating the development of transmission infrastructure.

However, the previous administration (2018-2024) stopped this mechanism, without explicitly revoking the reform, which remains enshrined in law. The result has been a lack of investment in renewable energy infrastructure, which has been cited as one of the main reasons for a low overall investment in the economy and a slowdown of the nearshoring process of North American companies relocating to Mexico.

As a complement to ensuring the transition of electricity generation towards renewable sources, the Secretary of Energy set up specific long-term targets for clean energy participation in electricity generation from 2020 to 2030, aligned with NDC objectives. This clean energy participation could be achieved through their own production assets or through the exchange of Clean Energy Certificates, which can be traded by independent renewable electricity producers. These certificates are awarded by a decentralized Energy Regulatory Commission.

CASE STUDY – ARGENTINA

The need of state planning to design comprehensive energy policies

The existence of laws and regulations with quotas is a necessary condition to induce renewable energy penetration; however, in many cases it may not be sufficient.

In Argentina, Law 27,191 (2015) established a periodic target for renewable energy in electricity consumption, aiming for 20% from renewable sources by 2025. The regulation explicitly mandates for large energy users to individually comply with the specified percentage of renewables in their consumption. Additionally, the government launched various tenders to incentivize the installed capacity of different technologies (RenoVAr) and implemented a bidding system known as *Mercado a Término de Energías Renovables* (MATER), among others. However, as of 2024, these quotas have not been met in any year, and energy experts believe that the 20% target is unlikely to be achieved. Neither the obligations for major electricity users nor the implementation of specific auctions have proven sufficiently effective. This is the combined result of several factors, including the impact of international shocks (such as the financial crisis, which caused many projects selected during the bidding process to be abandoned) and a lack of effective enforcement (including the absence of penalties for non-compliance with renewable penetration quota for large users). In addition, limitations in electricity transmission capacity create negative signals regarding the installation of new generation facilities.

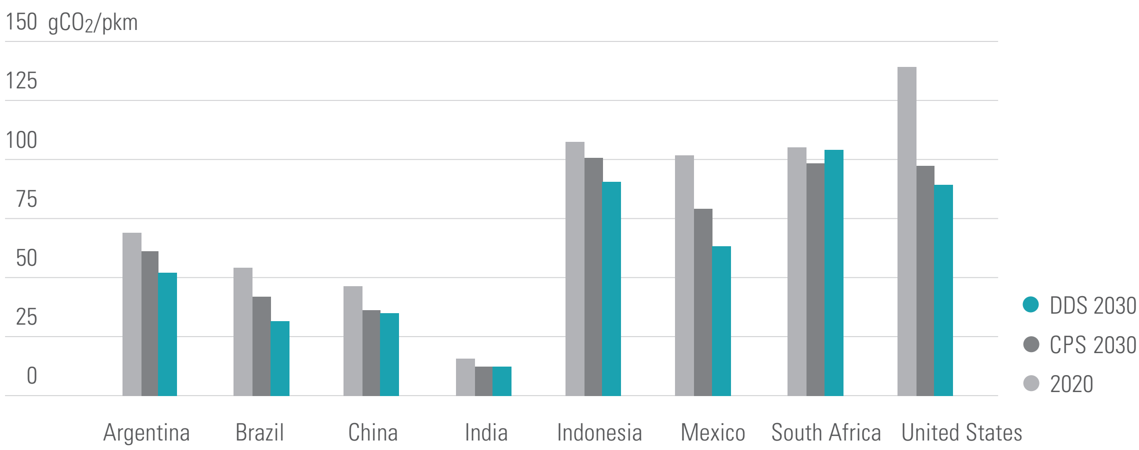
These recent experiences call for a careful evaluation to determine whether current private companies in various areas of the energy sector should be nationalized. This would then allow the enforcement of public planning investments, initially focusing on strengthening and expanding the high-tension transmission system through state-owned companies. Following this, tenders for renewable energy projects could be issued. This state-owned regulated natural monopoly would then also increase tax revenues, giving further support for comprehensive energy, climate and economic policies.

PASSENGER TRANSPORT

Passenger mobility is among the main emitting sectors in most countries, and mobility demand is expected to increase rapidly due to population growth and economic development. Therefore, decarbonizing the sector is a key component of national pathways to net zero. Given the significant inertia in the sector in its infrastructural and behavioral dimensions, decarbonization strategies should be implemented rapidly.

A variety of technical solutions are already available and could be developed without delay to reduce sectoral emissions, notably the shift to public transport (PT) and non-motorized transport (NMT) as well as the substitution of internal combustion vehicles with electric vehicles (EVs). Beyond their role in reducing CO_2 emissions, NMT and PT development policies offer important co-benefits such as improving public health by increasing active mobility among the population, reducing inequalities by lowering mobility costs, and alleviating car congestion and traffic jams. Furthermore, ongoing technical progress and cost reductions

Figure 14. Carbon content of passenger mobility (gCO_2/pkm; CPS VS DDS in 2030)



in EV technologies are expected to make them cost-competitive during this decade.

However, despite these apparently favourable conditions, current trends fall short of deploying these low-carbon options at the pace required in national pathways to net zero. While **Figure 14** shows that the carbon intensity of mobility decreases in most countries under current trends, national pathways to net zero highlight a significantly faster reduction in carbon intensity by the same date. In contrast South Africa is an example where the motorization rate increases faster than the electrification of cars in the DDS compared to the CPS.

The delay in sectoral decarbonization under current trends can largely be attributed to existing transport infrastructure and priorities, inherited from a sectoral paradigm favouring the development of car ownership and travel. In addition, electric vehicles remain unaffordable for middle and low-income households in many countries, leading these segments of the population to continue opting for internal combustion engine vehicles by default.

National pathways to net zero incorporate short-term targeted measures to counterbalance these trends and accelerate the shift towards low-carbon modes of transport and vehicles. Analyses of different countries show that the shift to PT and NMT depends significantly on targeted measures aimed at improving access, safety, speed, and quality of PT and NMT options, as illustrated in the Case study on Mexico. In addition, these analyses highlight that the shift to EVs relies heavily on targeted measures to reduce the upfront cost of EVs for consumers, to facilitate EV charging infrastructure, and incentivize car manufacturers to increase sales, as illustrated in the Case study on the US.

CASE STUDY – MEXICO

Accelerating non-motorized transport and public transport adoption by 2030

In Mexico, PT and NMT could meet the increasing demand for mobility by 2030. Key actions could be implemented immediately in the largest metropolitan areas to improve the access, safety, speed and quality standards of PT and NMT solutions, making them more attractive than private cars and accelerating their adoption.

Proposed measures include:

- reallocating road space to create dedicated lanes for PT and NMT on existing roads,
- converting road space into parking areas and increasing integration with PT and NMT services,
- regulating informal public transport to create higher quality standards for public transport through the creation of a charter of engagement, which would include incentives and associated command and control measures,
- updating planning and expenditure decision-making protocols to ensure that current road infrastructure investments are allocated only if correctly linked with safe and convenient PT and NMT alternatives.

Implementing these measures will contribute to improved quality of life and a better urban experience, enabling citizens to reclaim public spaces and continue to support local policies.

CASE STUDY – UNITED STATES

Short-term policies to accelerate EV adoption by 2030

In the US, federal, state, and local governments have implemented different policies and incentives aimed at accelerating the adoption of electric vehicles (EVs) by 2030. To incentivize EV uptake, the Clean Vehicle Credit under the Inflation Reduction Act (IRA) provides up to $7,500 to reduce the upfront cost of EVs. The credit is structured to ensure that it benefits the US workforce, requiring EVs to meet strict battery assembly and mineral sourcing requirements. Several states, including California, Delaware, Maryland, and New York, also offer rebates and tax credits for purchasing or leasing a new or used EV, ranging from $1,000 - $12,000. In Maryland, these tax credits helped increase EV sales by more than 59% in 2023.[29]

To support the expansion of EV charging infrastructure, the IRA has a property credit aimed

29 https://www.mdot.maryland.gov/tso/pages/newsroomdetails.aspx?newsId=779&PageId=38 (2024).

at expanding access to EV charging stations in underserved areas. Additionally, the Bipartisan Infrastructure Law (BIL) allocates $10.7 billion for LDV EV charging infrastructure. The National Electric Vehicle Infrastructure (NEVI) Formula Program established by BIL, for example, provides funding for states to deploy EV charging stations, covering up to 80% of eligible project costs.[30] Cities have also implemented EV ready ordinances, requiring new buildings and major remodel projects to integrate EV charging infrastructure.[31] At the same time, many utilities offer discounted charging rates and rebates for customers to install EV chargers. [32][33]

Regulatory measures are also driving EV adoption in the short term. The EPA has finalized stringent multi-pollutant emissions standards for LDVs and MDVs of model years 2027 and later, increasing the average fuel economy of their fleets and correspondingly, new EV sales.[34] At the subnational level, California's Advanced Clean Cars (ACC) II legislation, adopted by 14 states, targets 68% electric passenger car sales by 2030 and 100% by 2035. Similarly, California's Advanced Clean Trucks (ACT) and Advanced Clean Fleets (ACF) regulations require an increased share of medium and heavy-duty EV sales between 2024 and 2035, and private and public fleets to phase in the use of zero-emission vehicles (ZEVs) starting in 2024. Corresponding commitments from automakers, for example Stellantis' partnership with California[35], and business fleet targets, like Amazon's plan to incorporate 100,000 electric delivery vehicles by 2030[36], further increase EV adoption. Together, these short-term policies from both federal and nonfederal actors form a comprehensive strategy to drive the penetration of EVs, build necessary infrastructure, and decrease overall transportation emissions by 2030.

30 https://afdc.energy.gov/laws/12744
31 https://www.columbus.gov/Services/Public-Utilities/About-Public-Utilities/Office-of-Sustainability/Equitable-Electric-Vehicle-Parking.
32 https://www.alabamapower.com/residential/save-money-and-energy/energy-saving-products/electric-vehicles/ev-home-charger-rebate.html.
33 https://www.aelp.com/Energy-Conservation/Electric-Vehicles.
34 https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-multi-pollutant-emissions-standards-model
35 .California announces partnership with Stellantis to further emission reductions. California Air Resources Board https://ww2.arb.ca.gov/news/california-announces-partnership-stellantis-further-emissions-reductions (2024).
36 https://sustainability.aboutamazon.com/climate-solutions/transportation.

LAND USE AND FORESTRY

The land use, land use change and forestry (LULUCF) sector plays a critical role in achieving short-term emission reductions in all countries. In some countries, the national pathway to net zero shows significant immediate sectoral emission reductions, while in others, the annual CO_2 absorption levels of 2020 are maintained, ensuring negative sectoral emissions and highlighting the preservation of net carbon sinks. The DDS for all countries analysed in this context show negative LULUCF emissions by 2030, whereas in 2020 the sector is a net emitter in half of these countries (**Figure 15**).

In countries where sectoral emissions reduce significantly in the short term, the effective implementation of current policies plays a critical role.[37] A policy can be formally adopted by a policymaking institution without being effectively implemented by line ministries or other governmental agencies. Improving the implementation of a policy requires formal adoption to be accompanied by

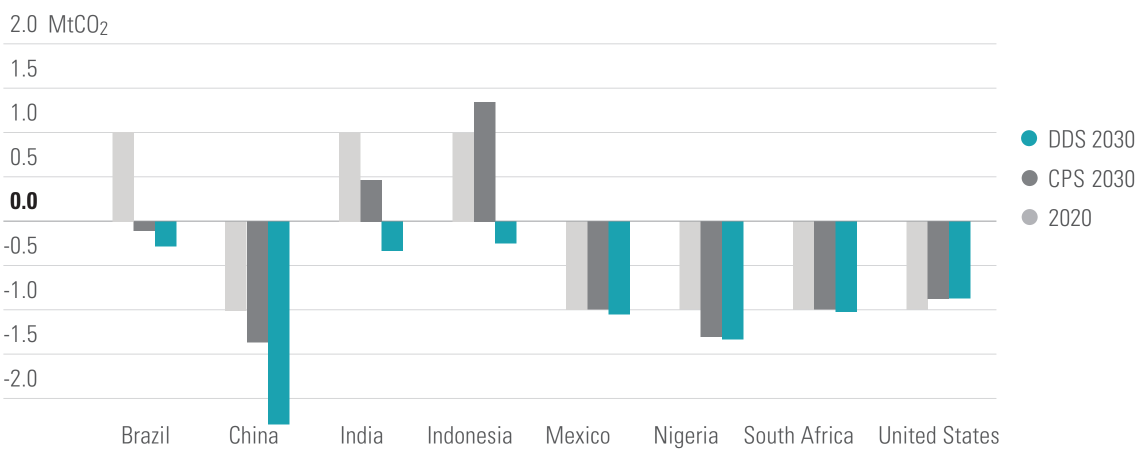
37 In Brazil's case, the CPS assumes that the current effectiveness of policy implementation continues, while a variation of the CPS assumes that the implementation of policies targeting deforestation improves, leading to a faster reduction in deforestation in this alternative CPS.

a clear designation of responsibilities within the public administration, as well as ensuring that the responsible institutions receive sufficient training, budget and appropriate tools for policy execution. It also requires that the effects of the policy are monitored, evaluated and that feedback is integrated. Policy implementation in LULUCF poses significant challenges, given that actors in agriculture and forestry are predominantly small-scale and that policies often address large territories.

Across Brazil and Indonesia, more effective implementation of forest conservation laws leads to a sharp decline in deforestation by 2030 in their DDS, as well as reductions in peatland fires and degradation in Indonesia. In India, an improved implementation of the existing afforestation programme and policies on participatory management drives afforestation and a significant increase in agroforestry by 2030 (Case studies on Brazil, Indonesia and India for more detail).

However, additional sectoral policies are required to achieve emission reductions compatible with carbon neutrality, with a focus on increasing the finance available to sectoral actors. The DDS in Brazil, India and Indonesia all achieve deeper net emission reductions in LULUCF than the respective CPS due to the adoption of additional policies. In Brazil, the reduction in deforestation is similar in the variation of the CPS and the DDS, but reforestation/afforestation and improvements in the management of standing forests occur at an accelerated pace due to improved financial incentives for land managers, particularly through the implementation of the Brazilian carbon market. In Indonesia, a key additional policy assumption in the DDS compared to the CPS is a strengthened system for payments for ecosystem services, which provides stronger incentives for land managers to conserve existing forests and integrate more perennial vegetation into their land. In India, the difference between the emission reductions achieved in the CPS and the DDS by 2030 can be attributed to afforestation and reforestation efforts, as well as an increase in carbon sequestration on croplands. This is supported by policies that strengthen the technical and financial support for farmers to adopt tree planting for energy production alongside crops and to establish energy plantations on wastelands (Case studies on Brazil, Indonesia and India for more detail).

Figure 15. CO_2 emissions from LULUCF ($MtCO_2$)



* Values are normalized to 1 for countries where LULUCF net emissions are positive in 2020, and to -1 for countries where LULUCF emissions are negative in 2020. For Brazil, the CPS shown in the graph is a variation of the CPS which assumes improvement in the implementation of policies targeting deforestation, which contributes to faster eemission reduction compared to the standard CPS.

CASE STUDY – BRAZIL

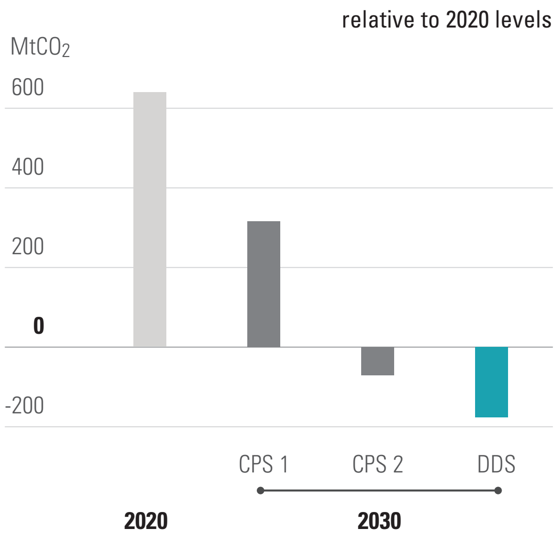
2030 mitigation strategy for LULUCF

The Brazilian LULUCF scenarios clearly illustrate the significant mitigation potential that can be achieved by improving the implementation of existing policy mixes the sector. The current policy scenario in Brazil assumes that existing deforestation policies remain in place without further additions. These policies include strengthened public monitoring and enforcement of forest protection laws, such as the 2012 Forest Code, which aims to reduce deforestation and protect Brazil's vital ecosystems. The Forest Code requires landowners to set aside between 20% and 80% of their property for nature conservation, with the exact percentage varying by biome (80% in the Amazon biome and 20% in the Cerrado and Atlantic Forest). While complete success in implementation has not yet been achieved in the current policy scenario (CPS1), past experiences in reducing deforestation suggest that, despite their flaws, these policies are likely to lead to a moderate decrease in LULUCF emissions from deforestation. In this scenario, mitigation is projected to reach 318 $MtCO_2$/year (from 637 to 319 $MtCO_2$) between 2020 and 2030 (**Figure 16**).

By improving the implementation of existing policies in LULUCF, the sector can achieve emissions of -73 $MtCO_2$ by 2030 through reduced deforestation, representing an additional 396 $MtCO_2$/year, in the variation of the current policy scenario (CPS2) (**Figure 16**). The main difference between the CPS and its variation lies in the effectiveness of policy implementation, which depends on government enforcement capacity and the availability of financial resources.

The Brazilian case also shows that to achieve net emission reductions in LULUCF by 2030 that align with long-term carbon neutrality goals, additional policies must be adopted to complement existing policy mixes. In the Brazilian DDS, LULUCF emissions decrease from 637 to -177 $MtCO_2$ between 2020 and 2030 – a reduction of 104 $MtCO_2$/year (**Figure 16**). Deforestation is reduced at the same pace as in the more ambitious current policy scenario (GPS2). However, the DDS assumes more drastic improvements in the management of standing forests, increased protected areas (Conservation Units and Indigenous Lands), and the implementation of a carbon market allowing for LULUCF offsets for private native forest areas. In Brazil's case, while the CPS2 scenario includes policies to protect forests, there are insufficient financial incentives for land managers to conserve or sustainably manage ecosystems on their land. In addition to the effective implementation of existing policies in the land use sector, the Brazilian deep decarbonization scenario assumes improved access to finance for land managers who engage in conservation or sustainable management practices on their land.

Figure 16. Emission change in LULUCF by 2030 in Brazil



CASE STUDY – INDIA

The effect of improving implementation of existing policies and strengthening the policy mix for enhancing carbon sinks

In the current policy scenario, LULUCF emissions in India are projected to decrease from -150 to -204 $MtCO_2$/year between 2020 and 2030. The main drivers of this reduction include increased carbon storage in trees and soils of croplands, as well as afforestation/reforestation. India is currently seeing improvements in the implementation of its policies impacting LULUCF, and the CPS assumes that these trends continue. A portfolio of policies is currently being implemented in the LULUCF sector, including the national forest policy, participatory forest management, the national bamboo mission, and the Nargar Van Yojana (Urban forests), to name just a few. For instance, the Nagar Van Yojana (Urban Forests) policy launched in 2020-21 for a five-year period (2024-2025) initially targeted the creation of 200 urban forest parks. However, due to an effective implementation that exceeded expectations, this target has been updated to 1,000 urban forest parks by 2024.

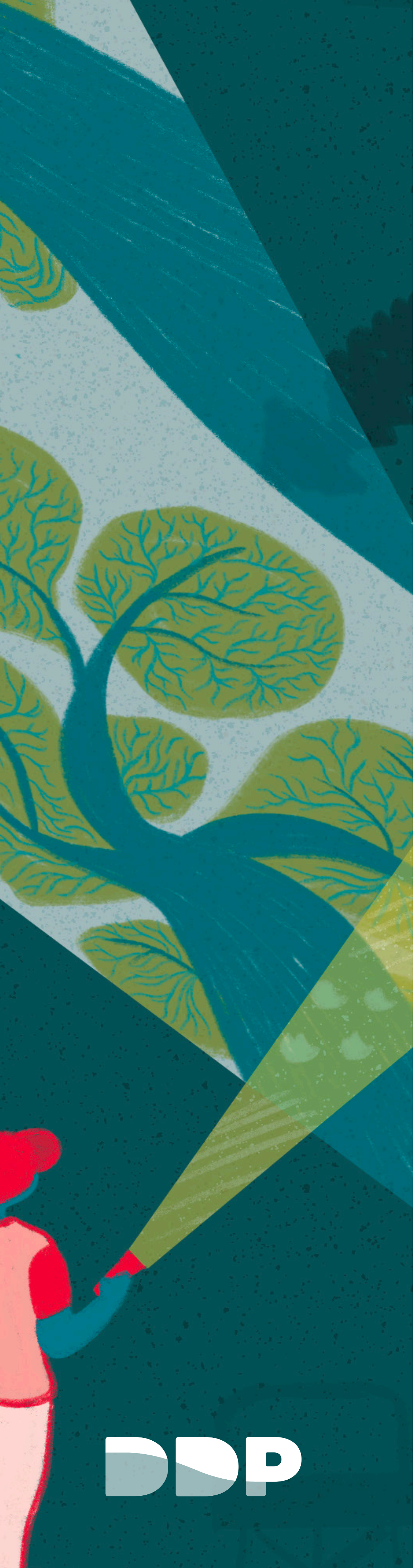
In the ENDC scenario, LULUCF emissions decrease from -144 to -345 $MtCO_2$/year, which is 141 $MtCO_2$/year more than in the CPS. This is due to accelerated afforestation/reforestation and an increase in carbon sequestration on croplands. India's DDS assumes that new policies will be introduced in the LULUCF sector, which will help achieve the additional mitigation and increased forest cover. Policies promoting tree-based energy plantations on wastelands contribute to increasing the forest cover, and a general policy on energy plantations is extended to include plantations on croplands, supporting farmers to grow trees for energy production alongside their crops. This is expected to supplement farmers' income in the long run, although they may need initial financial support to adopt agroforestry practices. This policy has been tested at a pilot stage in the state of Maharashtra, where subsidies are provided to farmers under the Employment Guarantee Act for cultivating bamboo alongside other crops.

CASE STUDY – INDONESIA

Transforming LULUCF into a net carbon sink by 2030 and aligning with global climate targets

In the current policy scenario for Indonesia, LULUCF emissions decrease from 303 to 120 $MtCO_2$/year between 2020 and 2030. The main drivers are a reduction in deforestation rates, especially in illegal and unplanned deforestation, as well as reduced peatland/forest degradation and afforestation/reforestation. The scenario assumes no additional policy measures in LULUCF; rather, these transformations are driven by the assumption that existing policies and regulations in the LULUCF sector will be better enforced and more effectively implemented, for instance forest conservation policies and policies that strengthen forestry surveillance to reduce illegal logging, policies that promote the restauration of peatlands and mangroves, and continued reforestation and natural forest regrowth at slightly increased rates.

In the DDS, LULUCF emissions decrease from 303 to -37 $MtCO_2$/year between 2020 and 2030, which is 157 $MtCO_2$/year more than in the current policy scenario. This additional reduction is achieved through accelerated actions to halt deforestation, enhance afforestation/reforestation, and more rapidly reduce peatland degradation. These transformations are supported by the introduction of new and more ambitious policies, including stricter deforestation bans, limits on peatland emissions, stronger land-use governance, and more aggressive restoration targets for peatlands, mangroves, and degraded forests. It is also assumed that conservation efforts will be significantly scaled up, along with economic incentives for ecosystem services which involve stronger mechanisms for payments for ecosystem services (PES), biodiversity conservation, and the integration of land-use policies with climate mitigation goals. A more rapid expansion of forest cover is expected through afforestation, reforestation, and agroforestry practices, aligning land use with climate targets and promoting the rapid adoption of more climate-friendly agricultural practices and further integration of carbon sequestration into agricultural systems, including much larger scale restoration efforts for peatlands and mangroves.



Immediate actions in national pathways to net zero

ACCOMPANYING STRUCTURAL ECONOMIC AND INDUSTRIAL SHIFTS

National pathways to net zero entail structural changes in economic and industrial systems. Turning these transformational challenges into opportunities for development requires determined country-specific action at the national level but also a proactive search for partnerships and international cooperation

The global transition to net zero necessitates fundamental shifts in the economic system, driven by the decline of carbon-intensive activities and the concurrent emergence of new industries that provide the goods, technologies and services required for the low-carbon transition. The resulting structural changes in national economies will significantly impact employment, production assets, and trade.

In absence of dedicated actions, significant macroeconomic tensions may arise in national economies, particularly in the most carbon-intensive countries. These tensions can be linked to trade imbalances, especially for countries that are heavily reliant on fossil fuel export revenues today, or through deindustrialization. New dependencies could also emerge in accessing low-carbon technologies if local economies are unable to produce them domestically. However, the new global economy, transitioning towards carbon neutrality, can create opportunities for some countries to implement structural changes in their domestic industrial structure. These changes can simultaneously enhance local industrialization and promote decarbonization, as demonstrated in the case studies of Mexico, South Africa, Indonesia, and Nigeria where both added value and job creation have been observed. Maximizing these potential macroeconomic and industrial benefits while minimizing the risks of the transition will often depend on the adoption of adequate measures to direct investments towards green industrial and economic development. These measures should align domestic socio-economic development objectives with the broader context of global change. A diverse range of economic sectors could be involved depending on country circumstances and priorities, such as the mineral value chain industries (Case study - Indonesia), solar PV value chains and other renewable energy components (Case study - Mexico, Indonesia, South Africa, Argentina), chemical industries (Case study - Argentina), and the iron and steel industries (Case study - South Africa). To implement such industrialization and effectively guide investments, countries can adopt a variety of public policies suited to their specific national circumstances. These may include public procurement with local content requirements, subsidies, public loans, or importation bans and duties (Case study - South Africa, Indonesia and the United States).

However, these structural transformations and associated national policies can also generate tensions at the international level, potentially leading to fierce competition among States if they are adopted unilaterally. The risk is particularly acute in the current global context and could undermine both the effectiveness of domestic policy actions and the broader global transition. To avoid this situation, countries must design and implement their national policies in a context of continuous dialogue with other countries and the search for mutually beneficial partnerships. International cooperation, for example, is critical to making the transition away from fossil fuels economically feasible for fossil fuel-dependent countries like Nigeria (Case study - Nigeria). Furthermore, innovative approaches to international cooperation (DDP, 2023)[38] are key components of the steel decarbonization strategy in South Africa, which serves as a model for mutually beneficial outcomes for both the country and its international partners (e.g., Europe) provided that coordinated policy actions are taken (Case study - South Africa: Green steel).

38 https://ddpinitiative.org/ddp-annual-report-2023/

CASE STUDY – SOUTH AFRICA

Economy-wide effects of localizing renewable energy value chains

South Africa has a highly coal-dependent energy system, faces significant energy security challenges, and has an economy characterized by high levels of poverty, inequality, and joblessness. At the same time South Africa has vast renewable energy potential and has expressed its commitment to decarbonizing its energy system in a pathway aligned with the international goal of limiting warming to well below 2°C (i.e. a long-term net zero CO_2 emissions trajectory). Linking low-carbon technology deployment to broader development goals in South Africa is critical. The localization of renewable energy components is a potential strategy to mitigate the negative impacts (e.g., job losses in the coal sector) while simultaneously enhancing the benefits of a net zero transition in South Africa's coal dependent energy system. Utilizing the hybrid energy-economy model SATIMGE, we examined various localization levels as South Africa progresses towards decarbonization by 2050.

Findings show that all localization strategies yield positive economic impacts in the short term (up to 2030), without significantly affecting renewable energy capacity expansion. An ambitious target of 70% local production could create between 18,700 and 25,500 jobs and add R3.5 to R6 billion to GDP (approx. $0.20 billion to $0.34 billion). A moderate target of 55% local production could generate 11,200 to 12,800 jobs and boost GDP by R1.87 to R2.93 billion by 2030 (approx. $0.1 billion to $0.17 billion). Minimum values are reached when localization significantly impacts the final price of products (resulting in a high price premium), while maximum values are reached when no price premium is considered. In the long run by 2050, the effects of the ambitious localization target are expected to amplify as the economy transitions towards net zero, with increasing local production of sub-products potentially creating up to 254,400 jobs and a R69.7 billion increase in GDP (approx. $3.5 billion), assuming no price premium.

The effect of the price premium on local content is also expected to be amplified in the long-term. When the price premium is held at 40% up to 2050, the net gains from ambitious localization are reduced to 32,700 jobs and GDP (approx. $0.51 billion). This demonstrates that achieving carbon neutrality will require South Africa to implement industrial changes in the short term (by 2030) if the country aims to localize its renewable production. These industrial changes must occur in the short-term (by 2030), when price premiums effects are still low, allowing for the realization of economies of scale in the long-term. If localization is not anticipated and occurs rapidly only after 2030, then economies of scale may not be realized and a price premium could persist into 2050. The rising costs of renewable energy investment due to highly uncompetitive local content has the potential to offset most of the benefits of increased localization if local manufacturing fails to establish a competitive advantage in the long-term, despite the widespread deployment of renewables to reach net zero.

Localizing the manufacturing of renewable energy components in South Africa (specifically, the components that can be produced domestically) has the potential to boost the economy and create employment, particularly on a low emissions pathway. Reasearch from the University of Cape Town underscores the need for support mechanisms to build competitive advantage and support increased localization in the renewable energy component manufacturing sector. Strategies to achieve this could include increased public procurement with local content requirements, incentives such as special economic zones and subsidies, as well as import duties on renewable energy components.[39]

39 Tatham et al - 2024 - Assessing the economy-wide effect of localising renewable energy value chains in South Africa. (https://zivahub.uct.ac.za/articles/report/ESRG_Working_paper_-_Assessing_the_economy-wide_effect_of_localising_renewable_energy_value_chains_in_South_Africa/25867093?file=46459039)

CASE STUDY – US

Guiding structural industrial changes in the energy sector

The US has taken significant steps in this direction with the adoption of the Inflation Reduction Act (IRA) in 2022.[40]

For example, through IRA's Energy Infrastructure Reinvestment category, the Department of Energy has identified key characteristics of energy projects that align with the long-term energy transition. The act finances projects aimed at repurposing and replacing energy infrastructure that has ceased to operate due to the energy transition, providing $250 billion in loans to fund the construction of renewable energy facilities in regions where coal-fired power generation once took place. These projects are expected to create jobs and generate income for the local economy and communities affected by these closures. In addition, the IRA also offers bonuses for renewable energy projects developed in energy communities, provided that they meet certain wage and apprenticeship requirements.[41]

These subsidies, loans, and bonuses are essential for guiding economic investments towards the energy transition, and creating positive socioeconomic impacts to balance the negative ones associated with the decline of existing carbon-intensive activities.

CASE STUDY – MEXICO

Macroeconomic impacts of localizing solar panel value chains

In Mexico, solar power generation could play a critical role in the energy transition. Directing investments towards domestic solar panel production and related services can facilitate the national energy transition and create new jobs to mitigate declining employment in traditional fossil fuel industries.

According to modelling results published by the UN Economic Commission for Latin America and the Caribbean (ECLAC/CEPAL),[42] using a scenario comparable to the DDS, the potential increase in jobs due to the energy transition in Mexico is around 8%, while job losses would be approximately 6%, implying a net employment gain of 2%. Job creation benefits from the energy transition in Mexico are further supported by a study conducted by the US National Renewable Energy Laboratory (NREL)[43], which found that if Mexico were to implement large-scale renewable energy projects, it could create over 72,000 new jobs. In addition to creating jobs, this investment would also lead to lower electricity production costs and significant benefits for the national electricity system, including a reduction in greenhouse gas emissions and other pollutants that adversely affect public health.

Hence, total employment does not need to be a barrier to the structural shift and may even become a net beneficiary. However, changes in activity across different sectors will require policies dedicated to ensuring a just transition and guiding the relevant investments.

CASE STUDY – ARGENTINA

Pro-active industrial policies to unlock development opportunities linked to the global "carbon neutral" economy

For Argentina, achieving carbon neutrality while ensuring sustainable economic development requires a careful balance between short-term actions and long-term growth strategies. Short-term measures must not only avoid harming economic development but should also lay the foundation for Argentina to capitalize on the global shift toward a "carbon-neutral" economy. These processes should be guided by proactive industrial and macroeconomic policies designed to strengthen current initiatives and create conditions to unlock new opportunities.

Argentina possesses significant potential for renewable energy production, particularly in wind and solar, but to maximize this potential, it is essential to implement policies that encourage

40 https://www.energy.gov/lpo/inflation-reduction-act-2022
41 https://www.irs.gov/newsroom/irs-issues-guidance-for-energy-communities-and-the-bonus-credit-program-under-the-inflation-reduction-act
42 https://repositorio.cepal.org/server/api/core/bitstreams/e776cadf-97b2-409e-9a1f-4c7e9923c31f/content
43 https://www.nrel.gov/docs/fy22osti/82580.pdf

greater local value-added participation in production and supply chains. By integrating local industries into the global renewable energy value chain, Argentina can ensure that the benefits of the green transition are broadly distributed, driving domestic job creation and economic diversification.

Moreover, as highlighted by the National Secretariat for Strategic Issues (2023)[44] and GIZ (2024)[45], Argentina is well-positioned to develop its chemical industry (with strong local human resources) through power-to-X (P2X) conversion technologies that utilize its hydrogen potential and local CO_2 sources. These resources can be converted into more complex molecules, such as synthetic fuels (e.g. kerosene for aviation or methanol and ammonia for maritime transport), addressing decarbonization in hard-to-abate sectors. This same industrial capacity could also be harnessed to produce chemicals and fertilizers from sustainable sources, further supporting the country's transition to carbon neutrality.

By combining its renewable energy potential with advanced industrial policies, Argentina can ensure that its pathway to carbon neutrality is not only environmentally responsible but also a driver of long-term socioeconomic development.

CASE STUDY – INDONESIA

Downstreaming the Indonesian mineral industry

Indonesia is endowed with abundant mineral resources, including 16 billion tonnes of gold, 10.5 billion tonnes of silver, 7.7 billion tonnes of iron, 16 billion tonnes of copper, 17 billion tonnes of nickel, 6.6 billion tonnes of bauxite, 7.1 billion tonnes of tin, 1.3 billion tonnes of titanium, and 0.55 billion tonnes of quartz. Today, these resources are primarily extracted and sold directly to the export market, with only a limited amount being processed, refined and manufactured into intermediate or finished products by national industries.

In 2021, Indonesia published its long-term climate strategy to achieve net zero by 2060, while satisfying domestic socio-economic objectives. According to the analysis, development pathways to net zero will require a massive deployment of electric vehicles (EVs) and the electrification of energy devices combined with zero-carbon electricity generated from solar photovoltaic (PV) panels, among other solutions. This transition will therefore require a significant increase in the use of batteries and solar energy systems.

According to the analysis, the Indonesian mineral mining industry, combined with the development of modern smelters and processing and manufacturing industries for these minerals, could fulfil the national demand for batteries for EVs and solar panels for the decarbonization of the power system. For example, processing domestic silica sand into solar cells could support the development of local solar PV production.

This "downstreaming" of the mineral value chain has been supported by the Government of Indonesia since 2020. National policy, specifically Law No.3/2020, and its recent implementation through Regulation No.25/2024, officially bans the export of raw materials and provides several facilities and incentives for local companies to create downstream mineral industries. This government policy and strategy are expected to optimize the use of national resources and reduce the importation of critical green technologies, while at the same time increasing the value added of the battery industry by up to 64-fold and the value added of stainless steel production by as much as 9.5-fold, potentially creating hundreds of thousands jobs by 2045.

44 National Secretariat for Strategic Issues (2023). Estrategia Nacional para el Desarrollo de la Economía del Hidrógeno. https://www.argentina.gob.ar/sites/default/files/2023/07/estrategia_nacional_de_hidrogeno_-_sae.pdf

45 GIZ (2024). CO_2 sources for PtX production in Argentina. https://ptx-hub.org/wp-content/uploads/2024/05/International-PtX-Hub_202405_CO2-Sources-Argentina.pdf

CASE STUDY – NIGERIA

Macroeconomic outlooks of international aid on Nigeria's net zero futures

Over the past two decades, Nigeria's GDP growth has slowed, failing to return to the levels seen in the early 2000s despite recovering to pre-pandemic trends by 2021.[46] The Nigerian government projects a growth rate of 3.75% for 2023, contrasting with the World Bank's more conservative estimate of 2.9%, reflecting challenges such as high borrowing costs, underperformance in the non-oil sector, and declining oil production. Unemployment, particularly among the youth, remains a significant concern, peaking at 28.1% in 2019 (World Bank Data).[47]

With its economic structure and natural resources, Nigeria has a high energy intensity. Its unique position as both a crude oil-exporting and oil products-importing country (due to limited refining capacity) highlights the complex interplay between its energy sector and the macroeconomy.[48] As the 14th largest oil producer globally and the second in Africa,[49] Nigeria had an average daily production of 1.5 million barrels in 2021. It is also the third largest producer of natural gas in Africa, behind Algeria and Egypt, and ranks 17th worldwide.[50] The oil and gas sector, contributing approximately 7.3% of Nigeria's GDP and 55% of its trade balance in 2022, underscores the economy's dependency on this sector.[51]

The transition away from the oil and gas sector will significantly impact Nigeria's economic structure and industry. The DDS assumes that the trade deficit will gradually converge to -1% in 2035, down from its observed level of -3.5% in 2021, and then remain constant until 2060 (the net zero year). Such a current account constraint in the context of declining oil and gas export capacity would significantly hinder the growth of the Nigerian economy. To counter this detrimental trend, a scenario was developed within a more favorable macroeconomic context.[52] The scenario suggests a positive non-price competitiveness (trade) shock corresponding to successful economic diversification. The trade shock applies to all scenarios, although the DDS benefits from a more relaxed trade deficit objective. The additional trade deficit permitted for the DDS corresponds to the differential in energy supply investment between the DDS and the CPS. This assumption aims to convey the implicit conditional nature of the net zero emissions target of the DDS on international aid.[53]

The modelling results suggest that emission reductions under the DDS are achievable with a GDP loss of 3.5% and employment losses of 3.2% in 2060, compared to the current oil and gas-based economy. However, by complementing the DDS with international aid, the gap between the energy supply investment requirements of the CPS and DDS can be bridged, allowing GDP and employment performances to align with those of a gas based-economy while reducing emissions to a residual 16 million tonnes of CO_2 equivalent ($MtCO_2eq$) in 2060. Conditional to international aid amounting to $880 billion (2021 value) over 39 years—amounting to an average of 1.1% of Nigerian GDP from 2022 to 2060—Nigeria may be tempted to shift from the shortsighted development path of a gas economy towards a transition towards a net zero, energy-sustainable economy. The international aid will help support sustainable investment (e.g. renewable energy, electrified transport infrastructure and the decarbonization of industries) to diversify Nigeria's economy.

46 The Nigerian Observer, 2023. World Bank projects Nigeria's economy to decelerate to 2.9% in 2023. https://nigerianobservernews.com/2023/01/world-bank-projects-nigerias-economy-to-decelerate-to-2-9-in-2023/ (accessed 20 February 2022)
47 The World Bank's World Development Indicators.
48 OPEC (2021) Nigeria facts and figures, Annual Statistical Bulletin. Available at: https://www.opec.org/opec_web/en/about_us/167.htm
49 Annual petroleum and other liquids production, U.S. Energy Information Administration. Retrieved 15 April 2022.
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CASE STUDY – SOUTH AFRICA

National and international perspectives on green steel, as an opportunity to decarbonize the steel sector while supporting domestic industrialization

South Africa needs to develop, and its steel industry is an essential component of the country's economic future. The pace at which green steel production processes are advancing is rapid – green steel was seen as impossible, and the sector was regarded as 'hard to abate' as recently as 2018. Now almost every major steel producer in the world is engaged in green steel projects and R&D. This pace will continue, if not accelerate, as pressure mounts on countries to decarbonize, and international trade mechanisms are introduced to penalize fossil-based producers (as currently being attempted by the EU's Carbon Border Adjustment Mechanism (CBAM)).

The cost for green steel technology is expected to continue declining. However, the main driver of production costs is the energy source, and South Africa is among the leading countries in terms of renewable energy resources. This positions South Africa favourably in terms of pricing for green steel production, making it one of the most cost-effective options for export to the international market. As green steel export facilities are established in South Africa, the ability to produce effectively for the local market will increase over time.

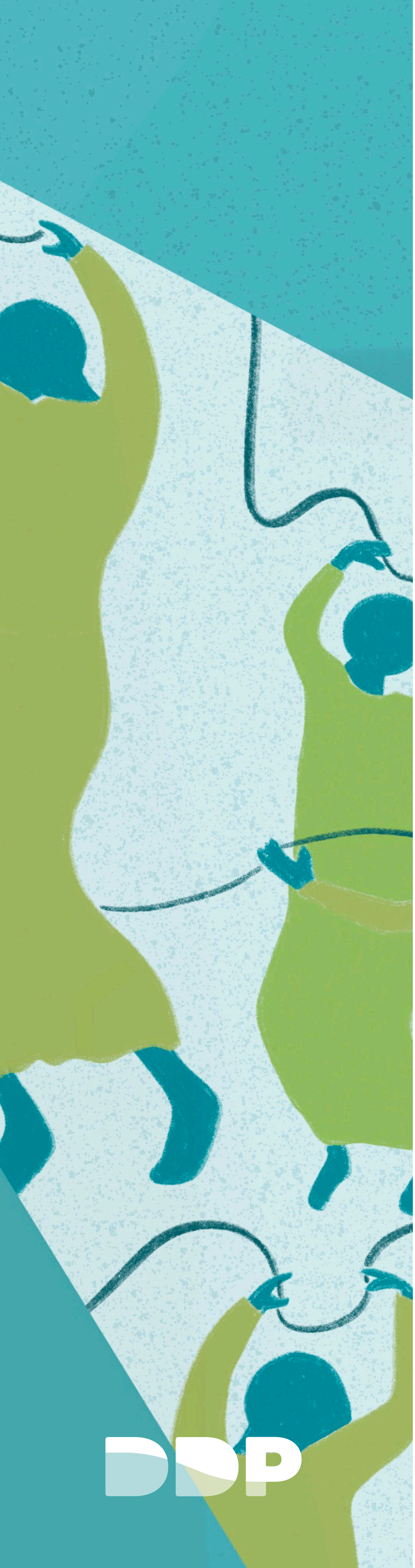
The DDS scenario for South Africa shows that the development of the green steel industry can be an efficient approach to achieve domestic decarbonization while simultaneously supporting effective industrialization with all its developmental benefits. However, for this to succeed, South Africa will need policies to promote industrial competitiveness of local green steel production to both capitalize on South Africa's comparative advantage in making green steel for export, while also to ensure that local green steel production is cost effective compared to cheap fossil-based steel imports.

However, there is also a critical dimension of international cooperation to consider. Current policies in many developed economies, including the European Union and the United States, may inadvertently hinder this potential. By heavily subsidizing domestic green steel production, these nations risk preventing African countries from capitalizing on crucial opportunity for green industrialization, while also potentially compromising their own energy security. The economic and security rationale for this approach is questionable. Developed nations aiming to produce green steel domestically will need to import both iron ore and green hydrogen. This is particularly challenging for the EU, which faces a significant deficit in the renewable energy capacity required for green hydrogen production.

An alternative, more globally efficient and secure approach would involve developed economies promoting Hot Direct Reduced Iron (HDRI) production in the most suitable locations, including African countries rich in both iron ore and renewable energy potential. This strategy offers multiple benefits:

- Economic Efficiency: It would reduce the overall cost of green steel production, enhancing the economic viability of the global transition to low-carbon steel.
- Enhanced Energy Security: By diversifying the locations of primary iron production and relying on easily transportable and storable Hot Briquetted Iron (HBI) instead of volatile hydrogen imports, this approach could significantly improve energy security for developed nations.
- Accelerated Decarbonization: Leveraging the most efficient production locations could expedite the global transition to green steel.
- Development and Industrialization Opportunities: This would provide African nations with a chance to leapfrog into green industrialization, supporting economic growth, job creation, and the development of industrial ecosystems.
- Supply Chain Resilience: A more distributed production network would enhance the resilience of global steel supply chains, reducing vulnerability to regional disruptions.
- Climate Justice: This approach would align climate action with development goals, addressing long-standing economic inequities.

Critics may argue that this approach poses a risk to employment in developed economies. However, it is important to note that the steel industry is rapidly automating, and the number of jobs in primary iron production is relatively small. Furthermore, by fostering a more competitive downstream steel industry and related manufacturing sectors, this approach could potentially increase overall employment in developed nations. The challenge now lies in creating policies that support green industrialization in developing nations while also enhancing global energy security. This could involve redirecting a portion of the funds currently earmarked for domestic subsidies to support the development of green iron capabilities in African nations. It might also entail creating preferential trade agreements for green HBI imports or establishing joint investment funds for HDRI projects in Africa.



Immediate actions in national pathways to net zero

MANAGING THE SOCIO-ECONOMIC TRANSITION

National pathways to net zero require short-term measures to prevent development delays, with a focus on supporting disadvantaged and vulnerable populations during the transition. These measures, which must be tailored to the unique contexts of each country, can be macroeconomic or sectoral in nature, possibly involving international cooperation.

National pathways to net zero entail socio-economic challenges in the transition, primarily driven by price increases that can undermine the affordability of basic needs (e.g., energy and transport) in the absence of short-term substitution opportunities. Such price surges can occur even without climate policies; however, ambitious climate action, if not managed carefully, can trigger rapid price surges alongside constraints on carbon, particularly affecting energy. These effects disproportionately affect the disadvantaged and vulnerable, who are more sensitive to cost fluctuations and may therefore lose access to basic services. If not addressed specifically, such a situation can significantly exacerbate inequalities and undermine the acceptability of the low-carbon transition.

This calls for the adoption of policy packages, combining mitigation measures aimed at reducing emissions with social and economic measures constructed to ensure a sustainable and equitable transition. These policy packages must be country-specific and tailored to the unique circumstances of each country. They are particularly crucial in the short-term to mitigate the socially negative impacts of stringent mitigation actions needed to initiate the low-carbon transition on a large scale.

Given this acknowledgment, the introduction of carbon pricing, whether through taxes or quotas, which will be one of the critical policy levers to reduce CO_2 emissions in all countries, must be considered alongside accompanying measures that address its potentially disproportionate impacts on low and middle-income households. These accompanying measures could include macroeconomic and fiscal reforms, such as using tax revenues to reduce labor taxes or providing direct transfers to the most affected households. This overall package can be consistent with efforts to reduce inequalities while simultaneously reducing emissions (Case study - Brazil).

CASE STUDY – BRAZIL

Bridging the gap - carbon markets and the promise of a fairer Brazilian economy

Brazil's labor market is characterized by high and distortive taxes alongside rigid laws that significantly impact its dynamics. These labor taxes, among the highest in the world, combined with stringent labor laws, contribute to considerable economic distortions. Despite recent labor market reforms in Brazil, many of these laws, established decades ago, are now outdated and ill-suited to the evolving nature of work in the 21st century. They often fail to address the flexibility required by modern businesses and the gig economy, leading to a high rate of informal employment. These factors underscore a critical need for reform in Brazil's labor regulatory framework to better align with current and future economic realities.

In Brazil's DDS scenario, revenues generated from the carbon market present a strategic opportunity to address these distortions in the current fiscal system and directly assist low-income families who are likely to be impacted by rising prices of goods and services due to carbon pricing. Utilizing carbon tax revenues to reduce labor taxes is one effective approach. This reduction can incentivize job creation and has significant potential to decrease informal labor and reduce income inequalities, which is crucial since wages are the primary source of income for the poorest classes. By reducing labor taxes using the funds received from carbon-intensive sectors, more labor-intensive sectors will disproportionately benefit. In the long-term, this approach will contribute to a shift in the economic structure towards a more sustainable and low-carbon economy.

Additionally, allocating a portion of carbon revenues for direct government transfers (perhaps using the existing structure of Bolsa Familia)[54] to the poorest segments of the population is another viable strategy. These transfers would help offset the increased costs of living caused by higher prices, thereby helping to maintain or even improve the purchasing power of these vulnera-

54 https://www.gov.br/mds/pt-br/acoes-e-programas/bolsa-familia

ble groups. This dual approach not only promotes a fairer transition to a low-carbon economy but also supports economic inclusivity, ensuring that the transition does not disproportionately burden those least able to bear the associated costs.
Data presented in the **Figure 17** highlights significant long-term gains in purchasing power across all household classes in Brazil by 2050, especially for the poorest 20%, whose purchasing power is projected to more than double. This aligns with strategies to use carbon market revenues for reducing labor taxes and providing direct transfers, suggesting that such fiscal adjustments could accelerate economic inclusivity and resilience in transitioning towards a low-carbon economy. These strategic measures promise to enhance the lives of the most vulnerable, making Brazil's economic growth more equitable and sustainable.

The accompanying measures can also involve implementing voluntary policies and actions to offer alternative, more affordable options if basic needs become too expensive under ambitious mitigation strategies. Along the same lines, measures can be taken to enhance the affordability of low-carbon options for low-income households through targeted policy instruments. For example, in passenger transport, targeted measures can be adopted to develop efficient, low-carbon options such as public transport, enabling low-income households to substitute their car travel with this cost-effective alternatives. Furthermore, financial support can be provided to help low-income households purchase low-carbon vehicles under preferential conditions that would make these typically more expensive options accessible. Examples of such accompanying measures include subsidies and investments as well as comprehensive policies promoting sustainable transport, or financial incentives, such as rebates and zero-interest loans, which can be reserved for specific household categories (Case study - United States).

CASE STUDY – UNITED STATES

Accompanying measures in the low-carbon transition of the passenger transport sector

The DDS envisions the expansion of public transit systems and subsidized mobility options to get a more equitable distribution of economic gains. The reduction in mobility costs will significantly benefit low-income populations and is a direct result of improved public transit infrastructure and the promotion of more affordable, sustainable transport options. In addition, state land-use reforms and zoning initiatives aim to create compact, less car-dependent communities. These efforts are expected to decrease the need for personal vehicle use and lower overall mobility demand compared to the current policy projection.
Significant subsidies and investments in public transport are designed to further reduce the direct costs of bus and rail trips, making these options more competitive with private car usage. Enhanced public transit systems, supported by comprehensive policies promoting sustainable transport, lead to a lower proportion of disposable income being spent on transportation, encouraging a

Figure 17. Projected impact on purchasing power across household income classes

	2015	2020	2030	2050
Purchasing power HH1 (2015=1) (Poorest 20% of households, below the extreme poverty line in 2015)	1.00	1.05	1.46	2.46
Purchasing power HH2 (2015=1) (40% of households, below the poverty line in 2015)	1.00	1.04	1.38	2.17
Purchasing power HH3 (2015=1) (30% of households)	1.00	1.01	1.29	1.93
Purchasing power HH4 (2015=1) (Richest 10% of households)	1.00	0.98	1.23	1.80

shift towards more cost-effective and low-carbon modal choices. Public transport authorities and private companies are investing heavily in electric buses and trains as part of comprehensive efforts to decarbonize public transport systems.

There is also expected to be a more aggressive decline in the purchase prices of zero-emission vehicles (ZEVs) due to intensified government policies and subsidies, increased investment in renewable technologies, and enhanced international cooperation on technology development and climate initiatives. Financial incentives, such as rebates and zero-interest loans, are extensively used to make these vehicles accessible to a broader range of consumers. Moreover, the technical energy efficiency of vehicles continues to improve due to breakthroughs in battery density and regenerative braking systems.

The drive towards ZEV production is strengthened by stringent emissions regulations, significant government funding for clean vehicle research, and a shift in consumer preferences towards sustainability. These factors converge to position ZEVs as a central focus of the automotive industry's future development plans.

Both public and private EV infrastructure are expected to further develop nationally, supported by the enhanced Bipartisan Infrastructure Law (BIL) National Electric Vehicle Infrastructure funding program, along with building code reforms that facilitate the development of residential charging infrastructure. Moreover, exemplary ZEV promotion policies, such as California's Light-Duty Vehicle (LDV) and Medium/Heavy Duty Vehicle (M/HDV) ZEV sales targets and mandates, as well as subsidies for low-income communities like the ones established under the California Electric Vehicle Infrastructure Project, are envisioned to be adopted by numerous states.

The accompanying measures that specifically address the social dimensions of the transition may also be linked to international cooperation. This is particularly relevant when accompanying measures involve financial mechanisms, such as de-risking instruments or soft loans, which lower the cost of investments in the low-carbon transition and facilitate access to low-carbon options at reduced costs in low-income countries (Case study - Argentina). These internationally-driven accompanying measures can be combined with national industrial policies that focus on restructuring the domestic economy to better align it with the needs of the national population (cf. message 2.3).

CASE STUDY – ARGENTINA

The role of international cooperation in reducing the Levelized Cost of Energy (LCOE) and preventing negative impacts of decarbonization pathways

Decarbonizing the energy sector in Argentina will require significant investments in both supply (Renewable Energy (RE) power generation and transmission capacity) and demand (appliances and other final use electric devices). The Green Exports Scenario (GES) will demand at least $15 billion compared to the CPS to meet electrification requirements. In addition, private and public stakeholders in Argentina have identified financing as one of the sector's main barriers.

The increase in electricity costs resulting from a higher share of renewable energy is important for developing countries. According to IRENA (2023)[55], the Cost of Capital (CoC) is a major determinant of the total RE price, while the regional average CoC in mature markets, e.g. Europe (4.4%) and North America (5.4%) is lower than in emerging markets, e.g. Latin America (6.9%), primarily due to differences in country risk premiums. There is a need for a redefinition of financial markets to support energy decarbonization in low and medium-income countries. De-risking investments is essential in countries that typically receive low credit ratings, leading to high interest rates on loans.[56] Development banks can significantly lower the CoC in emerging markets, as they have done in developed markets. In line with this approach, the GES models international cooperation as soft loans, which provide lower CoC for wind, solar,

55 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2023/May/IRENA_The_cost_of_financing_renewable_power_2023.pdf

56 Dixson-Declève, S., Rockström, J., Ghosh, J., Gaffney, O., Randers, J., & Stoknes, P. E. (2023). Earth for all. Actes Sud.

hydro and nuclear power plants. This results in a lower cost of electricity relative to other Scenarios, and higher growth rates for GDP and per capita GDP.

There are other costs associated with the transition, particularly related to technology substitution, which may have significant impacts and require additional policies. For example, soft loans aimed at facilitating the acquisition of electric appliances and targeted policies for low-income households are essential. This technological shift could also have a negative impact on the trade balance as many energy-efficient devices are imported into Argentina, highlighting the demand for additional industrial policies to counterbalance the effects.

Annexes

ANNEX 1
TABLE OF NATIONAL SCENARIOS AND REFERENCES

Country	Current Policy Scenarios (CPS)	Deep Decarbonization Scenarios (DDS)	References
Argentina	**The Current Policy Scenario (CPS)** This scenario illustrates the current policies mitigation actions in the energy sector (only energy sector was modelled with mitigation actions, the rest of the sectors follow the current trend). It includes ongoing actions (and some of the measures proposed in the framework of the Climate Change Mitigation Plan & Energy Plans) for energy sector decarbonization. Regarding Natural Gas, current trends are projected in terms of production, consumption & exports.It is not possible to reach GHG neutrality before 2050 in this scenario, due to limited action on hard-to-abate sectors, and economic restrictions to implement further measures.	**The "Green deal with cooperation" Scenario** This scenario illustrates some changes in the energy sector (the other sectors follow an historical trend) needed to enhance the Argentinean NDC targets, supposing an energy target of around 1.5 Ton/cap as mandatory for 2050. It includes some of the transformations needed (those that are possible considering the current situation) in some sectors This scenario supposes a favorable cooperation context: a world in which energy transition is a policy of convergence in terms of welfare and GDPpc & joint efforts for all economies to achieve both decarbonization and SDGs. The international cooperation is modelled as quotas for green exports & soft financing of energy industries activities for developing world. This allows Argentina to substitute the NG exports by low emission hydrogen and ammonia with a positive impact on GDP & GDPpc compared to CPS.	Deep Decarbonization Pathways in Argentina, 2024
Brazil	**The New Government Policy Scenario 1 (NGPS 1)** This scenario illustrates current policies implemented, with a limited success in halting deforestation. It does not allow to meet either 2025 and 2030 NDC objectives and does not increase long-term ambition up to 2050. **The New Government Policy Scenario 2 (NGPS 2)** This scenario is identical to the NGSP1, except for its better performance on halting deforestation. Therefore, it almost meets the 2025 NDC target and meets the 2030 target. Similarly to NGPS1, it does not increase long-term ambition up to 2050.	**The Deep Decarbonization Scenario (DDS)** This scenario illustrates the transformations needed to reach net zero all greenhouse emissions before 2050. It also reaches 2025 & 2030 NDC objectives. It only uses already available technologies (no CCS or technologies in R&D stages). Most of the efforts of the reductions of GHG emissions comes from changes in land use and forestry, and from carbon pricing.	Deep Decarbonization Pathways in Brazil, 2024
China	**The Current Policy Scenario (CPS)** this scenario represents the current policies in place and ongoing transformational trends which do not enable to reach the carbon neutrality before 2060.	**The GHG Net zero scenario (DDS GHG)** This scenario illustrates the transformations needed to reach net zero GHG emissions before 2060.	Deep Decarbonization Pathways in China, 2024
India	**The Current Policy Scenario (CPS)** This scenario encompasses all the on-going policies captured under the baseline scenario and the policies implemented after the NDC submission in 2015. In 2016, the government announced a major set of national sustainable development targets following the global Agreement on Sustainable Development Goals (SDG) in New York. These include but are not limited to electricity for all by 2019, 25 million LPG connections by 2019 (about 100 million achieved by February 2022), universal public health, universal primary education, and housing for all by 2022. This is in addition to selected sectoral, energy and climate action policies, with relevant Sustainable Development Goals (SDG) to be achieved by 2030.	**The Enhanced NDC (ENDC)** This scenario ratchets the on-going policies and NDC targets to capture the pledge made by India at COP26 to shift towards net zero emissions by 2070. This includes the targets below outlined in the Indian NDC as submitted in COP26. In this scenario, after 2030 all countries (including India) are assumed to implement ambitious climate policies aiming to meet the Paris Agreement goals of well-below 2 °C (and make efforts to below 1.5 °C).	Deep Decarbonization Pathways in India, 2024 Garg, A., Patange, O., Vishwanathan, S. S., Nag, T., Singh, U., & Avashia, V. (2024). Synchronizing energy transitions toward possible Net Zero for India: Affordable and clean energy for all.

Country	Current Policy Scenarios (CPS)	Deep Decarbonization Scenarios (DDS)	References
Indonesia	**The Current Policy Scenario with Low Growth (CPS LOW):** This scenario represents the current policies in place and ongoing transformational trends after the country reach ENDC in 2030 conditional targets. There is no additional policies and/or efforts to drive deep decarbonization transformations to reach long-term policy objective beyond 2060.	**The Deep Decarbonization Scenario with Low Growth (DDS LOW)** This scenario follows the same socio-economic growth than the CPS but considers additional policies and/or efforts to drive deep decarbonization transformations, reaching ENDC conditional target and net zero GHG emissions by 2060.	Deep Decarbonization Pathways in Indonesia, 2024
Mexico	**The Delayed NDC Scenario (D-NDC)** This scenario illustrates the policies needed in order to achieve Mexico's NDC targets, with implementation starting in 2025. It represents the current administration action and does not allow to reach all greenhouse emissions neutrality before 2050.	**The Delayed Deep Decarbonization Pathway (D-DDP)** This scenario illustrates the transformations needed to reach net zero all greenhouse emissions before 2050. It shows a delayed implementation of the mitigation actions, with most of the efforts made between 2030 and 2050, to reflect the current administration's delay. This scenario shows systemic changes: decarbonization is associated with positive impact on socioeconomic indicators (reducing poverty and inequalities, food security, improvement of the quality of life ...).	Deep Decarbonization Pathways in Mexico, 2024
Nigeria	**The Current Policy Scenario (CPS)** This scenario imagines an economy that is guided by the ambition of Nigeria's Energy Transition Plan and the country's Nationally Determined Contributions to mitigation in the framework of the UNFCCC process. Accordingly, by 2050, over 90% of power generation is attributed to renewable energy resources.	**The Renewable Energy Scenario (RES)** This scenario envisages ambitious emission reductions that allow Nigeria to reach a net zero objective by 2060. It assumes around 98% zero-emission energy penetration in the power sector by 2060.	Deep Decarbonization Pathways (DDP) for Nigeria's Low Emission Development up to 2060
Senegal	**The Business-as-Usual scenario** This scenario is defined as the continuation of historical energy demand and supply and no major improvement is assumed. In terms of the urban system, this scenario reflects a continuation of current forms of a weak organization in mobility, energy intensive building construction (for residential or professional use), and low waste management system (both solid and liquid), driven by a lack of change in land use planning, household behavior, business practices, and administrative structures (with increasing demands for transportation, construction, and waste management). Furthermore, the trend-based scenario highlights the persistent challenges facing the Senegalese food system in the absence of significant changes in agricultural policies, technological investments, and resource management practices.	**Greening of Universal Energy Access** This scenario rests on an acceleration of the greening of the energy supply with a strong penetration of renewable energies in the electricity supply as well as in productive sectors. By 2050, the scenario forecasts an increase in renewable energies in terms of installed capacity and production capacity. Their share in the electricity mix will be around 75%, with only 25% for natural gas. Renewable energies and gas will be used primarily. In addition to electricity production, clean, competitive, and diversified energies will be deployed in other economic sectors. The increase in energy demand is moderated by the implementation and application of energy efficiency policies. For the urban system including transport, housing and waste sectors, the scenario holistically integrates both supply- and demand side transformations. In terms of food systems, the scenario describes a trajectory where agroecology, productive agriculture, and conventional agriculture coexist and complement each other.	

Country and partners	Current Policy Scenarios (CPS)	Deep Decarbonization Scenarios (DDS)	References
South Africa	**The Current Policy Scenario (CPS)** This scenario does not allow to meet carbon neutrality by 2050. Shares of fossil fuels in global energy production decline moderately, but not substantially, with prices and demand following the IEA Announced Pledges Scenario (APS) projections. It takes places in a world with a slower transition to clean fuels, products and technologies, and more limited or no support to developing countries. This world comes with high risks that South Africa and other developing countries will be subject to pressure.	**The 9 Gigatonnes cumulative carbon budget (9GT) and 2050 net zero CO_2** This scenario allows to meet net zero CO_2 economy wide by 2050. Fossil fuel shares of global energy production decline significantly, particularly coal, and as a result demand and prices for natural gas and crude oil drop in line with the IEA Net Zero Energy scenario (NZE) projections. It takes place in a more ambitious climate world context with a strong multilateral rules-based regime, with stricter policies on carbon-intensive trade, a more rapid transition to EVs, reduced demand for fossil fuels and a greater market for 'green' export trade, and greater climate support for developing countries.	Deep Decarbonization Pathways in South Africa, 2024
United States	**The Current Policy Scenario (CPS)** This scenario reflects existing, on-the-books climate actions in the United States, at both federal and state level. Existing state-level renewable portfolio standards (RPS) and zero-emission vehicle (ZEV) sales targets, Corporate Average Fuel Economy standards, and IRA tax credits for renewable electricity generation, ZEVs, carbon capture and storage (CCS), and a methane fee on oil and gas facilities are among the key policy drivers in this scenario. It also reflects ongoing trends that reduce emissions but do not enable carbon neutrality before 2050.	**The Enhanced Ambition scenario (EAS)** This scenario expands upon Current Policies and includes new potential policies from both federal and non-federal actors that are designed to meet the current 2030 NDC and a 2035 NDC that is on the path to net zero. Some of the additional policy actions modeled include a full phaseout of unabated coal-fired electricity generation by 2030, accelerated adoption of ZEV in light-duty vehicle, bus, and freight truck markets, ramped up electric appliance standards, more stringent standards for oil and gas methane, as well as extensions of the existing IRA tax credits beyond their legislated sunset dates. This detailed policy pathway is extended from 2035 to 2050 by using a linear emissions constraint to approximately net zero.	Zhao, O'Keefe, Binsted, et al., 2024: Zhao et al., 2022; Joint Global Change Research Institute, 2024

ANNEX 2
SOCIO-ECONOMIC AND DEVELOPMENT NARRATIVES IN DDS, BY COUNTRY

This annex details the assumptions adopted by each country in their DDS for socio-economic and development dimensions. The approach to these questions is not standardized across countries. Rather, each national analyses focuses on some dimensions that are most relevant in the specific country context. These insights can be quantitative from the modelling of the DDS or more qualitative when grounded on the detailed definition of the narratives supporting the DDS.

Argentina

Between 2020 and 2050, Argentina's national economic situation is projected to improve, with GDP per capita increasing from $22,302 (Purchasing Power Parity, PPP) in 2020 to $51,703 (PPP) in 2050. Unemployment is projected to decline substantially, from 8% in 2020, to only 3.5% by 2050. Inequality is also expected to decrease significantly: the proportion of low-income households is expected to fall from 38% of total households in 2020 to zero in 2050, while middle-income households are predicted to grow from 54% to 80% of total households, and high-income households from 7% to 19%.

The reduction in income inequalities allows a larger proportion of households to reach a higher purchasing power, directly impacting their capacity to adopt more costly mitigation solutions, such as electrical vehicles (EVs) for passenger transport and heat pumps for residential buildings.

The population is estimated to grow at an average annual rate of 1.14% up to 2050. Urban population growth is expected to be 1.28%, while the rural population will decline at 1.47% up to 2050. This scenario occurs within a global context where all countries are actively engaged in achieving and cooperating on the Sustainable Development Goals (SDGs).

Brazil

Between 2020 and 2050, the economic situation in Brazil is projected to improve, from a GDP per capita of $15,759 (PPP) in 2020 to $30,757 (PPP) in 2050.

This represents a near doubling of GDP (a 95% increase), primarily driven by growth in the agriculture and services sectors. Meanwhile, primary industries undergo a gradual decline, while clean technology industries experience rapid expansion.

Debt is expected to stabilize, or even decrease, following fiscal reforms. In the long-term, however, an aging population poses risks that may lead to increasing debt. Real wages (adjusted for inflation) will more than double between 2020 and 2050, and the share of GDP paid as wages is also projected to increase. At the same time, unemployment rates are likely to stabilize as a result of political efforts directed at supporting emerging industries. Progressive taxation reforms are expected to reduce both income and wealth inequality. Furthermore, revenues generated from national carbon pricing will be used to support the purchasing power of those on the lowest incomes and to reduce labor taxes.

Brazil is experiencing a decrease in the rate of population growth, with a slight increase (10%) projected by 2050. This trend will lead to an aging demographic, with potential implications for healthcare and social services.

The decarbonization strategy in Brazil, which focuses on reducing emissions from the LULUCF sector and advocating for sustainable forest management, protects indigenous communities by safeguarding land rights, providing legal protection, and supporting traditional livelihoods.

China

The economic situation in China is projected to improve between 2020 and 2050, from a GDP per capita of $17,891 (PPP) in 2020 to $42,485 (PPP) in 2050. This growth is due to the rapid expansion of China's economy in the short to medium term, which is expected to reach approximately 218% of its 2015 magnitude by 2030. This expansion is expected to transition to a consistent growth trajectory, achieving 358% of the 2015 GDP by 2060.

However, the economic growth rate is forecasted to decelerate thereafter, culminating in a GDP that is 384% of the 2015 level by 2100, influenced by the dual challenges of a rapidly contracting population and significant demographic aging.

China's population will soon reach a peak of approximately 1.42 billion, before gradually declining to about 1.2 billion by 2060, and ultimately reaching roughly 790 million by the end of the century. The long-term contraction in population, along with pronounced demographic aging, will pose significant challenges for the country.

India

The economic situation in India is projected to improve between 2020 and 2050, with GDP per capita rising from $6,997 (PPP) in 2020 to $39,033 in 2050 (PPP). India's GDP is expected to rise exponentially, increasing by 510% between 2020 and 2050.

Several socio-economic development objectives have been achieved, including universal access to electricity by 2019 and the establishment of an LPG network with 100 million connections by February 2022.

The rate of population growth in India is slowing down compared to the period from 1990 to 2020, with a projected population increase of 20% between 2020 and 2050. Urbanization is progressing, and the share of the population living in urban areas is expected to increase from 31% in 2020 to 52.8% in 2050.

India is expected to reach the food security threshold of 2,100 kcal per capita per day; currently, the average is 2,160 kcal per capita per day, with projections indicating access to 2,280 kcal per capita per day by 2050, along with a more diversified diet.

Lastly, decarbonization of the power sector aims to provide clean and affordable electricity for all.

Indonesia

Between 2020 and 2050, the economic situation in Indonesia is projected to improve, from a GDP per capita of $11,857 (PPP) in 2020 to $72,366 (PPP) in 2050. The Indonesian government aims to achieve "developed" country status by 2045 as detailed in their *Golden Indonesia 2045 Vision,* with a focus on escaping the middle-income trap. The country seeks to reduce the unemployment rate to 4%.

The Indonesian population is expected to increase by 22% by 2050, at a rate slightly lower than recent historical trends. Urbanization is progressing, with the share of the population living in urban areas rising from 58% in 2020 to an estimated 70% in 2050.

This scenario depicts the development of downstream industries in Indonesia, increasing job opportunities in new green sectors with better working conditions. The development of renewable energy, particularly small solar PV systems in isolated islands, will contribute to increasing energy access for more Indonesians.

Indonesia aims to achieve food security by 2045, with the food security threshold set at 2,100 kcal per capita per day. Indonesians currently consume around 2,000 kcal per capita per day, and are expected reach an average of 2,600 kcal per capita per day in 2060, along with a more diversified diet. In parallel, food loss is projected to decrease from 16 million tonnes per year to 9.7 million tonnes per year by 2060. This reduction will be achieved through improved campaigns and educational initiatives on food waste.

Bringing an end to pollution and contamination are critical outcomes of effective waste management. Landfill waste is projected to decrease from 2030, down to zero by 2050 (meaning that no waste will be directed to landfills), with a maximum tolerance of 15% to 20%, which is similar to standards in other developed countries.

Mexico

Between 2020 and 2050, the economic situation in Mexico is projected to improve, from a GDP per capita of $19,473 (PPP) in 2020, to $36,255 (PPP) in 2050. Long-term global economic conditions, such as commodity prices, trade agreements, and financial markets, will affect the distribution of income, employment, wages, and economic growth. The structural evolution of the Mexican economy is expected to lead to a significant reduction in inequality, creating a virtuous circle of increased value-added, increased productivity, higher internal demand, and reduced inequalities. The implementation of a development model with a carbon neutrality objective will lead to an unemployment rate close to 3.6% in 2050, which is a little higher than the reference scenario (2.6%). However, the goal extends beyond simply achieving a low unemployment rate, it also emphasizes the importance of ensuring that jobs are productive, wages are fair, and working conditions are good. This is part of the broader challenge of promoting inclusive and sustainable economic growth.

The rate of population growth is slowing, with the population increasing from 112 million in 2010 and 125 million in 2018, to a projected 138 million in 2030. The economy will be affected by changes in the age structure of the population, which will affect labor productivity abd consumption patterns. This situation may lead to a potential "demographic dividend". However, from 2030 it is projected that the economic support ratio will decline steadily as the percentage of older individuals in the population increases. This new demographic structure could impact consumer behaviour, allowing for radical changes in urban infrastructure.

Indeed, cities would develop to become more "accessible" to all, with decentralized economic activities and services, and improved distribution of infrastructure and investments. Streets would be re-zoned and redesigned to meet community objectives, while new mobility schemes would promote alternatives to car transport. Furthermore, mixed land uses would be promoted to reduce unnecessary travel, and to integrate lower income populations into socio-economic development trends.

Nigeria

Between 2020 and 2050, the economic situation in Nigeria is projected to improve, from a GDP per capita of $5,499 (PPP) in 2020 to $31,556 (PPP) in 2050.

Expected national economic growth in Nigeria results from the combination of a growing active population (labor supply) and increasing labor productivity, with a real GDP growth rate of 5.41% by 2050. The unemployment rate decreases from 11% to 8% by the final year.

The industrialization depicted in this scenario promotes economic growth and poverty reduction while also creating quality green jobs and contributing to the reduction of greenhouse gas emissions and improving environmental sustainability. This pathway benefits the population as their access to affordable energy improves over the period.

Senegal

Senegal is currently a lower middle-income country, and the economic situation is improving drastically between 2020 and 2050, and the GDP/cap roughly doubles by 2050. For example, by 2030, the Gross National Product rate is expected to reach 6.5%.

A main dimension of development in Senegal is electricity access, which currently 35% of the population lack. The most ambitious scenario increases electricity production and distribution infrastructure to ensure universal electricity access around 2030.

Senegal's industry develops rapidly, especially sub-sectors allowing a domestic valorization of local raw materials, including from agriculture and from mining. This leads to economic growth and more employment in the industrial sector.

The demand for transport and housing increases significantly as the population gets richer. This demand is met by a supply that emphasizes public transport and electric mobility as well as buildings built from ecological materials.

Agriculture also undergoes a transformation to increase currently low productivity levels in order to better support the development of a national agro-industrial sector and reduce food imports. At the same time, the emphasis lies on increasing productivity with sustainable methods, and agro-ecology play a central role. Access to land and to formalized land ownership improves among Senegal's small-scale farmers, helping them to undertake the long-term investments needed for sustainably increasing the production.

South Africa

Between 2020 and 2050, the economic situation in South Africa is projected to improve, from a GDP per capita of $13,063 (PPP) in 2020 to $31,816 (PPP) in 2050. This growth is due to the improvement of the national economic situation, for example the output of the energy sector is 14% higher compared to the reference case. However, there are concerns about crowding-out effects in terms of investments: investments in mitigation may displace investment in other sectors.

This national perspective directly impacts the population: an increasing share of GDP is dedicated to wages, which are rising at a proportionally faster rate for low-income households, resulting in a reduction of poverty rates. Between 2030 and 2050, a significant increase in employment is expected, leading to a drastic decrease in the unemployment rate.

This all takes place alongside migration towards urban areas, which is expected to continue especially within the larger metropolitan cities, with the proportion of the population living in urban areas increasing from 67% in 2020 to 72% in 2030. By 2050, it is expected that 79% of the population will be residing in urban areas. There will also be a gradual reduction in the ratio of formal to informal housing.

Plans are underway to enhance public services with increased investment in health, education, and infrastructure. Electricity access is expected to increase across the period, from 87% in 2020 to 99% in 2050.

A key transformation in the passenger transport sector will involve fostering a sustainable transport culture, making public transportation attractive, affordable, and normative, while also considering the emerging trends in digital and connected transport practices. Such initiatives will also lead to the improvement of air quality in cities.

United States

Between 2020 and 2050, the economic situation in the US is projected to improve, from a GDP per capita of $64,317 (PPP) in 2020 to $120,402 (PPP) in 2050. The population is expected to increase by 28% between 2050 and 2010.

A more equitable distribution of economic gains is occurring, with enhanced support for lower-income households through more extensive public transit systems and subsidized mobility options. Significant investments in public services and social housing are aimed at combating gentrification and improving equity in urban and rural settings. The development of mixed-use spaces is prioritized to facilitate a closer integration of housing, work, leisure, and public services. This approach aligns with the societal shift towards sustainability and community-focused living. Engagement in community planning activities helps to tailor transportation solutions to the specific needs of diverse communities, enhancing overall quality of life and reducing transport-related stress and pollution.

The Deep Decarbonization Pathways initiative helps global and national decision-makers take actions towards a deeply decarbonized world with drastically reduced inequalities.It is an international collaboration of experts, who share common scientific methods to elaborate robust analyses and engage with stakeholders. The DDP is an initiative of IDDRI.
www.ddpinitiative.org

The IDDRI, Institute for Sustainable Development and International Relations, a Paris-based independent policy research institute, aims to integrate sustainable development into global relations and policies. It serves as a multi-stakeholder dialogue platform, facilitating discussions on critical shared concerns like climate change, biodiversity, food security, and urbanization. The institute contributes to creating development paths aligned with national priorities and sustainable development goals.
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