Rhodium Group

Rhodium Climate Outlook 2024: Probabilistic Global Emissions and Energy Projections

Energy & Climate

October 8, 2024

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Executive Summary

The first Global Stocktake under the Paris Agreement, which concluded one year ago, cautioned that the world was not on track to keep warming well below 2°C of temperature rise and called on countries to come forward with ambitious nationally determined contributions (NDCs) for reducing greenhouse gas emissions for the coming decade. It encouraged countries to set economy-wide emission reduction targets covering all greenhouse gases and sectors and aligned with nationally-determined pathways to net-zero emissions around mid-century.

As countries prepare to announce these 2035 NDCs in early 2025, it will be important to consider what each country is currently on track for, as a starting point for assessing what additional ambitious action can be taken to get on a pathway to net-zero emissions. There are two main obstacles to setting expectations for countries' 2035 NDCs: first, a lack of consistent and transparent baseline emissions projections across all major economies; and second, an inability to capture the uncertainty inherent in projecting the future of the global economy and its underlying energy dynamics. Without these, the international community has nothing against which to assess the level of ambition of proposed NDCs.

To fill this gap, the Rhodium Climate Outlook (RCO) provides a comparable and consistent measure of the likely evolution of greenhouse gas (GHG) emissions and energy trends in the world's major economies. RCO results are reported as a full probability distribution of outcomes against which to assess not only the most likely future, but the full range of potential outcomes given the inherent uncertainty in future economic growth, fossil fuel prices, and clean energy technology costs.

This year's edition of the RCO provides economy-wide greenhouse gas (GHG) emissions projections for all regions of the world and each of the G20 economies under four scenarios:

- The **RCO Baseline** illustrates what climate future the world is likely on track for absent a major acceleration in the pace of climate policy ambition or accelerated innovation in emerging technologies beyond their current trajectory. It is the starting point for assessing what additional action is needed to reach the global temperature goals in the Paris Agreement.
- The **Current NDC Scenario** explores a future in which countries all meet their unconditional NDCs by 2030, but countries' post-2030 levels of climate policy ambition largely follow the path they are on today.
- The **Current Mid-Century Commitments Scenario** illustrates the outlook for global emissions and temperature if all countries meet their 2030 NDCs and all countries achieve emission reductions consistent with a straight-line path to their current nationally-determined targets of net-zero emissions or carbon neutrality by mid-century.
- The **Expanded Net-Zero Commitments Scenario** goes even further by adding 2070 net-zero emissions commitments for all remaining countries and expanding commitments by those countries that have only set carbon neutrality commitments to cover all GHGs.

In this 2024 edition of the Rhodium Climate Outlook, we find that:

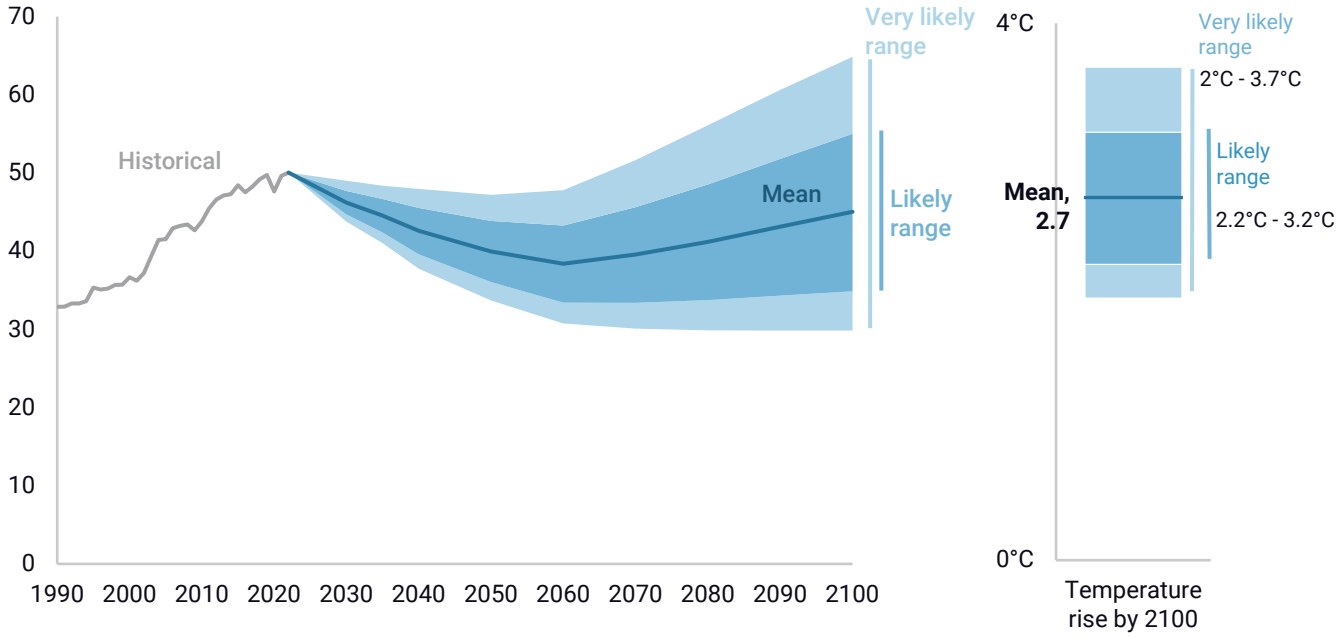
The world is currently on track to exceed 2°C, but we've avoided the most catastrophic projections

Shortly before the Paris Agreement was adopted in 2015, the Intergovernmental Panel on Climate Change (IPCC) estimated that without additional efforts to reduce emissions, global temperatures would increase between 2.5 and 7.8°C (*very likely* range, i.e. 90% confidence interval) by the end of the century. Policy and technological progress over the past nine years has significantly reduced the global temperature outlook. We now project in our **RCO Baseline** *very likely* temperature increases of 2.0-3.7°C by century's end, with a 2.2-3.2°C *likely* (i.e. 67% confidence interval) range, and 2.7°C on average (Figure ES1). However, if current trends in policy and technology development continue, we find there is a less than 7% chance of keeping global temperature increases below 2°C, a Paris Agreement goal. An acceleration in the pace of climate policy and technology development will be required to meet the temperature goals in the Paris Agreement.

FIGURE ES1

RCO Baseline Scenario: Global greenhouse gas emissions and temperature rise

Net emissions including removals (billion metric tons of CO_2-equivalent)



Source: Rhodium Climate Outlook, AR5 100-year GWP values. Following IPCC conventions, this report uses *very likely* to indicate a 90% probability of occurring and *likely* to indicate a 67% probability.

The world has made progress in decarbonizing electricity and vehicles, but barriers remain

Thanks to several decades of policy and innovation, the world has made considerable progress in decarbonizing power generation and transitioning from internal combustion to electric vehicles. We find that emission reductions in the power sector continue through 2060 in the RCO Baseline, as renewables grow by six to nine times today's levels by 2050.

At the same time, fossil-powered generation *likely* falls 34-77% below today's levels. But without ongoing support for variable renewable technologies, along with a significant acceleration in policy and innovation in clean firm generation (e.g., storage, enhanced and advanced geothermal, and advanced nuclear), fossil generation hangs on and even expands in the second half of the century. Underlying these global trends are stark differences between regions. OECD countries and China see the lion's share of renewable energy investment in the coming decades in the RCO Baseline, with variable renewables rising from a 14% share of total generation today to 67% by 2050 on average. In contrast, the rest of the world starts from a much lower base, with variable renewables growing from just 5% of total generation today to 40% by 2050 on average. Accelerating this progress and ensuring it reaches the rest of the world as well will require addressing barriers to renewable deployment, including transmission and siting issues in OECD countries and China, and access to capital in emerging economies.

Industrial emissions remain stubbornly high, despite some glimmers of hope

While emissions from the power and transport sectors fall, the industrial sector—including steel, cement, chemicals, and refining—faces stronger headwinds on its path to decarbonization. By 2050, industry consumes more fossil fuel than power generation, and emits more greenhouse gases than power, transport, and buildings combined. The good news is we see emissions fall in the coming decades in some of the highest-emitting sectors—including cement and iron and steel production—largely driven by growing adoption of low-emission technologies. But complete decarbonization of industrial production still requires a considerable acceleration in policy and innovation, and decarbonization of all other industrial sectors requires both technology innovation and deployment policy.

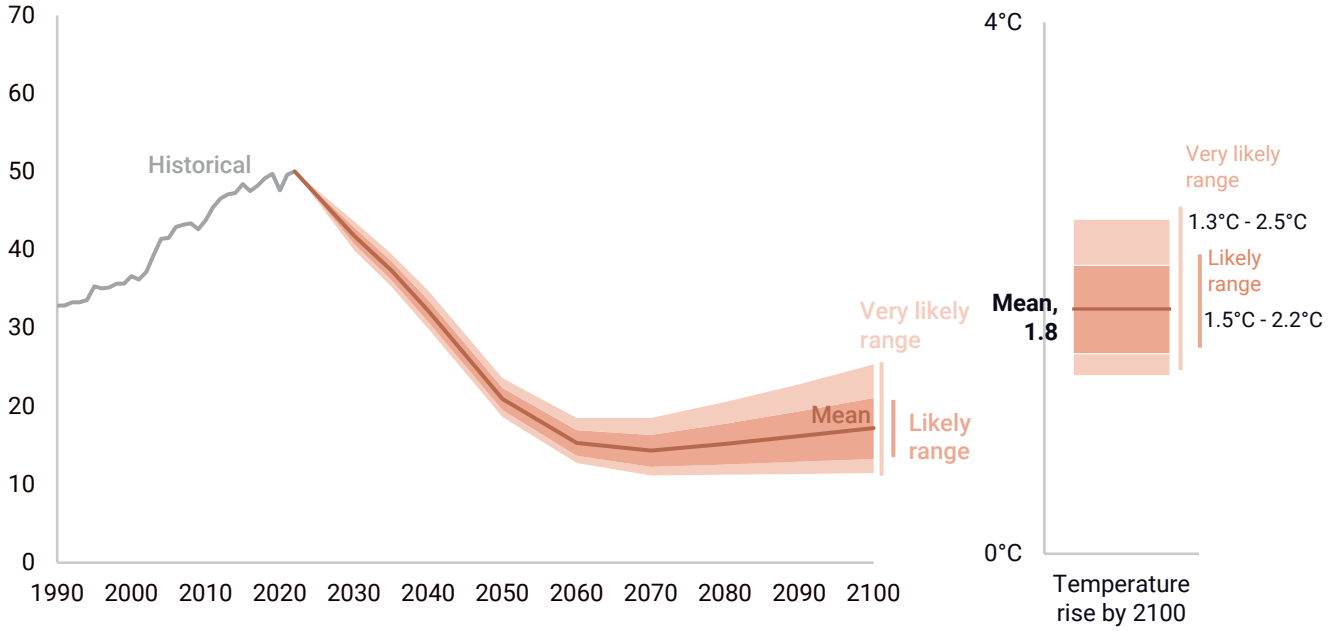
If countries meet their current mid-century emissions targets, odds of remaining below 2°C increase significantly

The outlook changes considerably from our RCO Baseline in a world in which countries accelerate their ambition in 2035 and beyond to stay on a path to reach their existing mid-century emissions targets. To date, 149 countries representing 88% of global emissions have set net-zero or carbon neutrality targets in law or other policy documents, or announced by the head of state, including China, the US, the EU, and India. Under this **Current Mid-Century Commitments Scenario**, we find that the world is *very likely* on track to see an increase in global mean surface temperature of 1.3-2.5°C and is *likely* on track for 1.5-2.2°C by century's end (1.8°C on average) above pre-industrial levels (Figure ES2). If countries meet their current near- and long-term emissions commitments, it increases the odds of keeping global mean temperature rise below 2°C from less than 7% to 68%.

FIGURE ES2

Current Mid-century Commitments Scenario: Global GHG emissions and temperature rise

Net emissions including removals (billion metric tons of CO_2-equivalent)



Source: Rhodium Climate Outlook. The Current Mid-Century Commitments Scenario illustrates the outlook for global emissions and temperature if all countries meet their 2030 NDCs and all countries achieve emission reductions consistent with a straight-line path to their current nationally-determined targets of net-zero emissions or carbon neutrality by mid-century. Following IPCC conventions, this report uses *very likely* to indicate a 90% probability of occurring and *likely* to indicate a 67% probability.

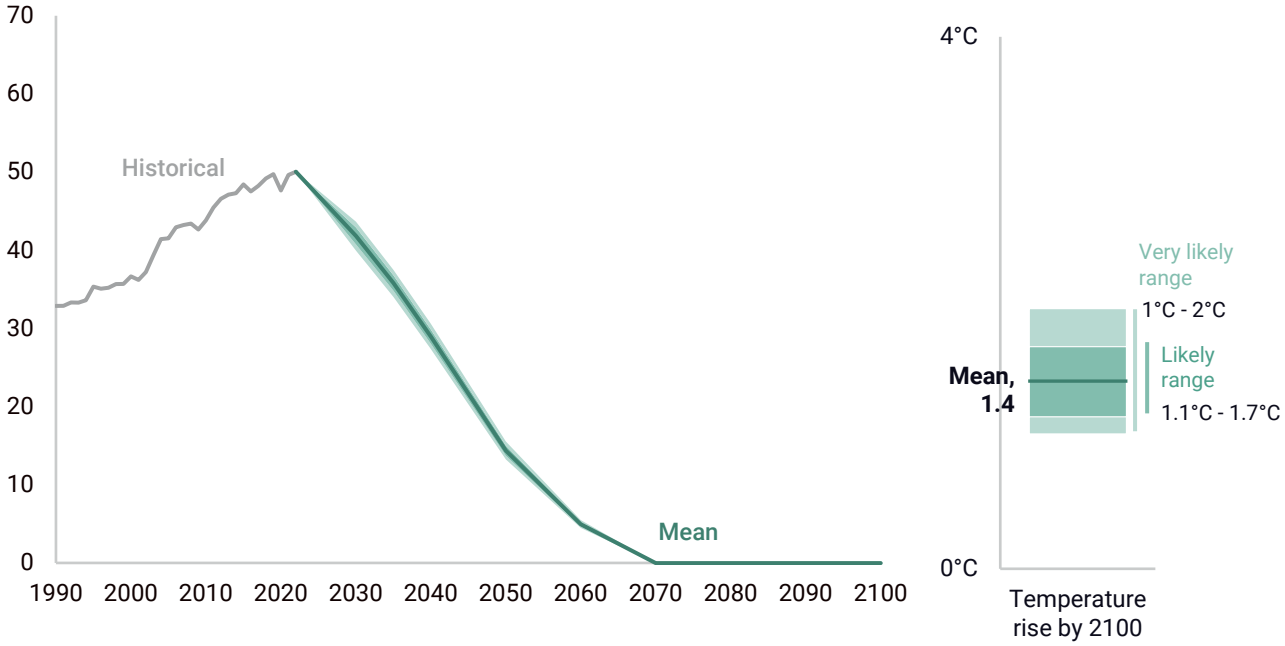
If all countries adopt net-zero GHG targets by 2070, odds of keeping temperature rise below 2°C by century's end jump to 96%

In our **Expanded Net-Zero Commitments Scenario,** all countries that do not yet have mid-century net-zero goals adopt targets of net-zero emissions by 2070, and countries with carbon-only targets (i.e., China and Saudi Arabia) include all greenhouse gases in their existing targets. Getting all countries to net-zero emissions by 2070 pushes up the odds of keeping end-of-century global mean temperature rise below 2°C to 96% and puts the 1.5°C end of century goal within reach, albeit with a mid-century overshoot. We find a 62% chance of keeping global temperature rise below 1.5°C by 2100 (1.1-1.7°C *likely* range) with an average overshoot of 1.7°C in 2050 (1.5 to 1.9°C *likely* range) (Figure ES3).

FIGURE ES3

Expanded Net-Zero Commitments Scenario: Global GHG emissions and temperature rise

Net emissions including removals (billion metric tons of CO_2-equivalent)



Source: Rhodium Climate Outlook. The Expanded Net-Zero Commitments Scenario adds 2070 net-zero emissions commitments for all remaining countries that don't currently have announced commitments, and expands commitments by those countries that have only set carbon neutrality commitments to cover all greenhouse gases. Following IPCC conventions, this report uses *very likely* to indicate a 90% probability of occurring and *likely* to indicate a 67% probability.

CHAPTER 1

What Are We on Track for?

Understanding what the world and nations are on track for today is a critical starting point for charting a path to where we need to be to avoid the worst impacts of climate change. Shortly before the Paris Agreement was adopted in 2015, the IPCC released its Fifth Assessment Report summarizing the state of climate science and the outlook for global emissions at that time. In this report, the IPCC found with "high confidence" that absent additional action to control GHG emissions, global temperatures would continue to rise, reaching 2.5 to 7.8°C by the end of the century (*very likely* range).[1] Against this backdrop, signatories to the Paris Agreement pledged to work together to limit global temperature increases to "well below 2°C" relative to pre-industrial levels, with an aspiration of limiting temperature increases to 1.5°C.

The Paris Agreement called for a five-year cycle to take stock of progress toward meeting these goals and inform decision-makers of where additional action is required. This first Global Stocktake cycle concluded last year at the UN Climate Change Conference in Dubai (COP28), where policymakers and stakeholders concluded that the world is not on track to limit warming to well below 2°C. To make up that gap, the Global Stocktake called on Parties to come forward with ambitious nationally determined contributions (NDCs) for reducing emissions the next five-year target cycle through 2035 and encouraged them to set economy-wide emission reduction targets covering all greenhouse gases and sectors, aligned with mid-century net-zero goals.

Setting ambitious 2035 targets

Setting ambitious 2035 NDCs that go above and beyond what countries are on track for today will be critical to ensure that we avoid locking in business-as-usual (BAU) emissions pathways over the next decade. As Parties prepare to announce their 2035 NDCs in early 2025, it will be important to understand what each country is currently on track for—its baseline emissions pathways under current policy and energy market trends—as a starting point for assessing what additional ambitious and achievable action can be taken to get on a pathway to net-zero emissions around mid-century.

One obstacle to setting expectations for countries' 2035 NDCs is a lack of methodologically consistent emissions projections for key economies to provide the international community with a solid set of baselines against which to assess the level of ambition of proposed NDCs. Countries' own projections, when made available, often lack transparency around the assumptions embedded in those projections—including the outlook for economic growth, a highly uncertain variable—making them difficult to assess and compare.

To fill this gap, in this year's edition of the Rhodium Climate Outlook (RCO), we provide methodologically consistent economy-wide GHG projections for all G20 economies through 2035. By assessing country-level emissions under a range of potential economic and energy market futures, the RCO provides a comparable and consistent measure of what the world's major economies are likely on track for, including a full probability

[1] Following IPCC conventions, this report uses *very likely* to indicate a 90% probability of occurring and *likely* to indicate a 67% probability.

distribution of outcomes against which to assess not only the most likely future, but the full range of potential outcomes given uncertainty in economic growth, fossil fuel prices, and clean energy technology cost trajectories.

Projecting an uncertain future

There has been a proliferation of global GHG emissions and energy outlooks in recent years. Most outlooks, however, have the following limitations for use by policymakers:

Single, deterministic scenarios: Most outlooks report outcomes under a single scenario (or set of scenarios) that are based on deterministic input assumptions for key variables that are, in reality, highly uncertain. The pace of economic growth, for example, is one of the most important drivers of emissions growth, yet most outlooks rely on a single deterministic GDP projection. Other important uncertainties that drive emissions include population growth, fuel prices, clean technology costs, and the pace of learning for emerging decarbonization technologies.

Policy bifurcation: Because of the inherent uncertainty in how policy will evolve over time, modelers are left to construct stylized emission projections that follow one of two possible policy stories: 1) countries keep policies in place today, but there is no further evolution of policy beyond that; or 2) countries fully implement the pledges they have announced, whether their near-term NDCs, mid-century net-zero targets, or global emissions scenarios consistent with 1.5°C. The reality is likely somewhere in between those two extreme policy stories.

Partial emissions picture: The majority of outlooks have focused to date on the energy transition, reporting emissions of carbon dioxide (CO_2) from energy combustion. But energy CO_2 contributes only two-thirds of global greenhouse gas emissions. The rest is emitted as methane (CH_4) from oil and gas production, agriculture and waste; nitrous oxides (N_2O) from agricultural production; hydrofluorocarbons (HFCs) and other fluorinated gases used in refrigeration, cooling, and industrial uses; and CO_2 from industrial processes, forests, and other land uses. Without an integrated understanding of the potential trajectory of emissions of the other third of GHGs, we are left with only a partial picture of what we are on track for.

No integrated temperature rise outcomes: Other available emissions scenarios project out to 2030 or 2050—the edge of known or announced policy pledges. This makes it impossible to provide an integrated set of global temperature rise projections, which require annual data through at least the end of the century. As a result, other modeling efforts do their best to align their 2030 (or 2050) projections with aggregate, global long-term emissions scenarios developed by other groups. This introduces cross-model structure and assumption inconsistency and provides limited information about what geographic, sectoral, or technological developments are most important in shaping global temperature outcomes.

Rhodium Climate Outlook

The RCO seeks to address these shortcomings with probabilistic energy, emissions, and temperature projections of use to a wide range of global stakeholders. We've done this

by incorporating the following innovations, which to our knowledge have not been combined in a single modeling platform to date:

- Probabilistic global and regional emissions projections that capture uncertainty in economic and population growth, oil and gas prices, and clean energy technology costs.
- An econometrically-based policy projection module that uses evidence of the determinants of climate policy around the world over the past two decades to provide probabilistic projections for how policy is likely to evolve going forward.
- Projections for all GHG emissions, not just CO_2.
- Probabilistic temperature projections derived directly from our emissions projections but including climate system uncertainty as well.

In the following chapters, we provide an overview of the results of our second annual RCO. In Chapter 2, we outline the outlook for global emissions and global mean surface temperature rise under our four global emissions scenarios. Chapter 3 dives deeper into the regional and sectoral dynamics in our RCO Baseline scenario. Chapter 4 provides a framework for assessing baseline emissions of G20 economies through 2035 and compares that to a straight-line path to reaching each economy's own mid-century targets.

CHAPTER 2

Global Climate Outlook

Greenhouse gas (GHG) emissions are produced from every single facet of the global economy, which makes projecting changes in global emissions over the coming decades highly uncertain. We don't have a crystal ball to know precisely what will happen to the drivers of emissions over time—economic growth, demand for energy and materials, fossil fuel prices, deployment of new clean energy technologies, and the evolution of climate policies. While this makes it hard to pinpoint exactly what emissions *will be* in 2050 (or 2100) with any certainty, characterizing these uncertainties in an integrated modeling platform can yield probabilistic energy, emissions, and temperature projections, providing valuable insight into where decarbonization is going well, and where efforts need more focus.

The Rhodium Climate Outlook (RCO) is produced using such an integrated modeling platform: Rhodium's Global Energy Model (RHG-GEM). RHG-GEM captures uncertainty in economic and population growth, coal, oil and natural gas prices, and clean energy technology costs under likely policy evolution to provide probabilistic energy, emissions, and temperature projections through the end of the century (see the Technical Appendix for more detail).

The result is our **RCO Baseline**, which provides probabilistic GHG emissions and energy outcome ranges based on the most up-to-date outlook for key drivers. This RCO Baseline illustrates what the world is likely on track for absent a major acceleration in the pace of climate policy ambition or accelerated innovation in emerging technologies beyond their current trajectory. It is the starting point for assessing what additional action is needed to go above and beyond what the world is already on track to achieve. The RCO Baseline should be used as a starting point for assessing:

- Where policy acceleration is most needed;
- Where expected cost reductions in mature clean technologies don't go far enough to deploy at scale in regions with slow-to-evolve climate policy;
- How the emergence of new technologies that are nearing maturity can further reduce emissions; and
- Where additional innovation is most needed and where new technologies would have the largest impact on future GHG emissions.

In this second annual Rhodium Climate Outlook, we complement our RCO Baseline projections with three additional scenarios. The first is a **Current NDC Scenario**, in which all UNFCCC Party countries meet their unconditional NDCs by 2030 and then continue on a path where climate policy ambition and technology development evolve over subsequent decades based on historical trends (but no major acceleration of ambition beyond the 2030 NDCs). This scenario demonstrates what the world is on track for today if all 2030 NDCs are met, but new NDCs largely follow what countries are already on track for.

An additional **Current Mid-Century Commitments Scenario** illustrates the outlook for global emissions if all Parties meet their 2030 NDCs and countries that have announced

commitments to net-zero emissions or carbon neutrality by mid-century achieve emission reductions consistent with a straight-line path to their goals. To date, 149 countries representing 88% of global emissions have established net-zero or carbon neutrality targets in law or other policy documents or announced by the head of state. This scenario quantifies the impact of all mid-century commitment countries aligning their 2035 and subsequent NDCs with a path consistent with achieving their nationally-determined mid-century goals.

Finally, the **Expanded Net-Zero Commitments Scenario** illustrates the impact of getting all countries on a path to net-zero greenhouse gas emissions between 2050 and 2070. In this scenario, we start with all existing net-zero targets that have been committed or announced to date. For countries that currently have carbon neutrality-only goals (i.e., China and Saudi Arabia), we assume they expand coverage to include all greenhouse gases within the same timeframe as their current carbon commitments. For all other countries that currently have no net-zero or carbon neutrality target, we assume they follow a straight-line path from their 2030 NDCs to net-zero GHGs by 2070.

In the rest of this chapter, we share global GHG emissions and associated temperature rise results through the end of the century under the four scenarios described above.

Global greenhouse gas emissions outlook

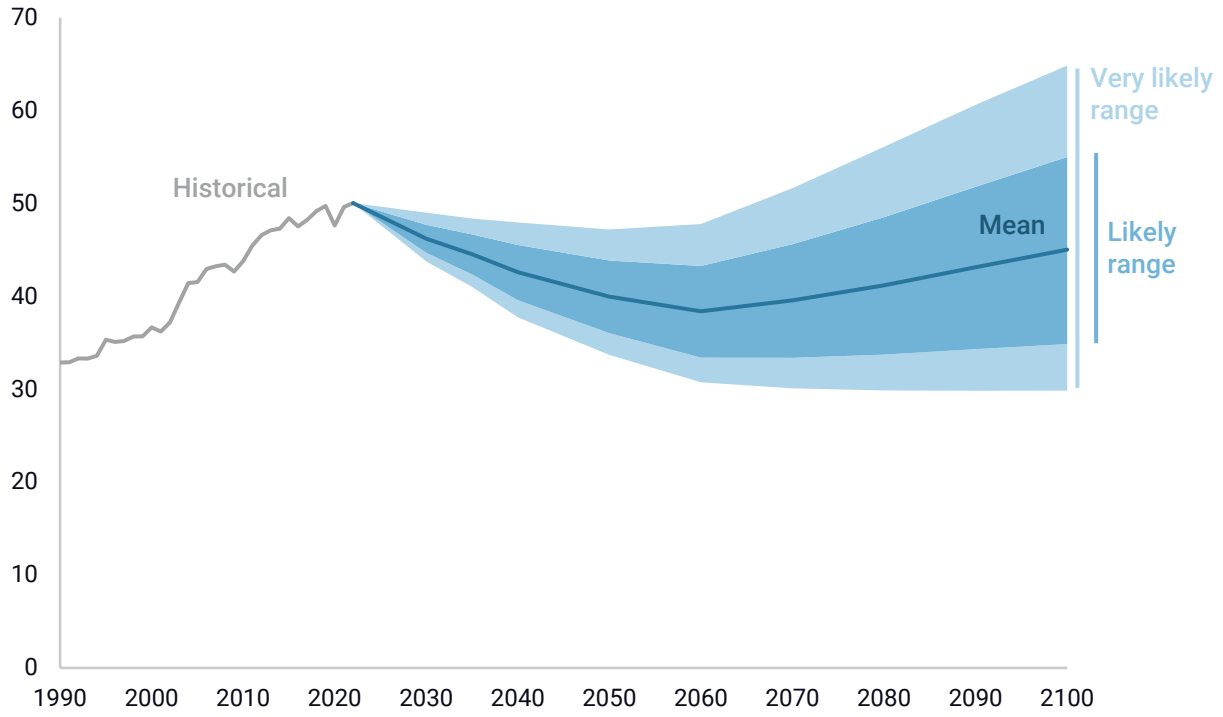
RCO BASELINE

Under the 2024 **RCO Baseline** scenario, we find that global GHG emissions are *likely* to decline through 2060 before flattening out, reversing and gradually increasing through the end of the century (Figure 1).[2] Taking into account uncertainty in the key drivers of emissions, it is *likely* (67% probability) that global GHG emissions decline to 42-47 gigatons of CO_2e by 2035—a drop of 3-7 gigatons below 2019 levels, or 6-14%. By 2050, emissions are *likely* to reach 36-44 gigatons, a drop of 6-14 gigatons below 2019 levels, or 12-28%. It is *very likely* (90% probability) that emissions will drop below 2019 levels by 1-9 gigatons (or 3-17%) and by 2.5-16 gigatons (or 5-32%) in 2035 and 2050, respectively. By 2100, uncertainty in key emission drivers increases, leading to a wider range of emissions outcomes, with global GHG emissions *very likely* somewhere between 30 to 65 gigatons of CO_2e, and *likely* between 35 to 55 gigatons.

The higher end of the *likely* emission range is characterized by a world with very high economic growth powered by cheap and plentiful fossil fuels and stubbornly high clean energy technology costs. At the lower end, emissions reductions are driven by lower economic growth and increasingly cheap and plentiful clean energy like renewables and electric vehicle (EV) batteries that out-compete fossil fuels in an environment of high oil and gas prices, paired with more ambitious climate policies.

[2] Projections are decadal, with 2030 as the first projected year. We model existing policies through 2030 and only apply our uncertainty framework from 2030 onward.

FIGURE 1
RCO Baseline: Global greenhouse gas emissions
Net emissions including removals (billion metric tons of CO_2-equivalent)

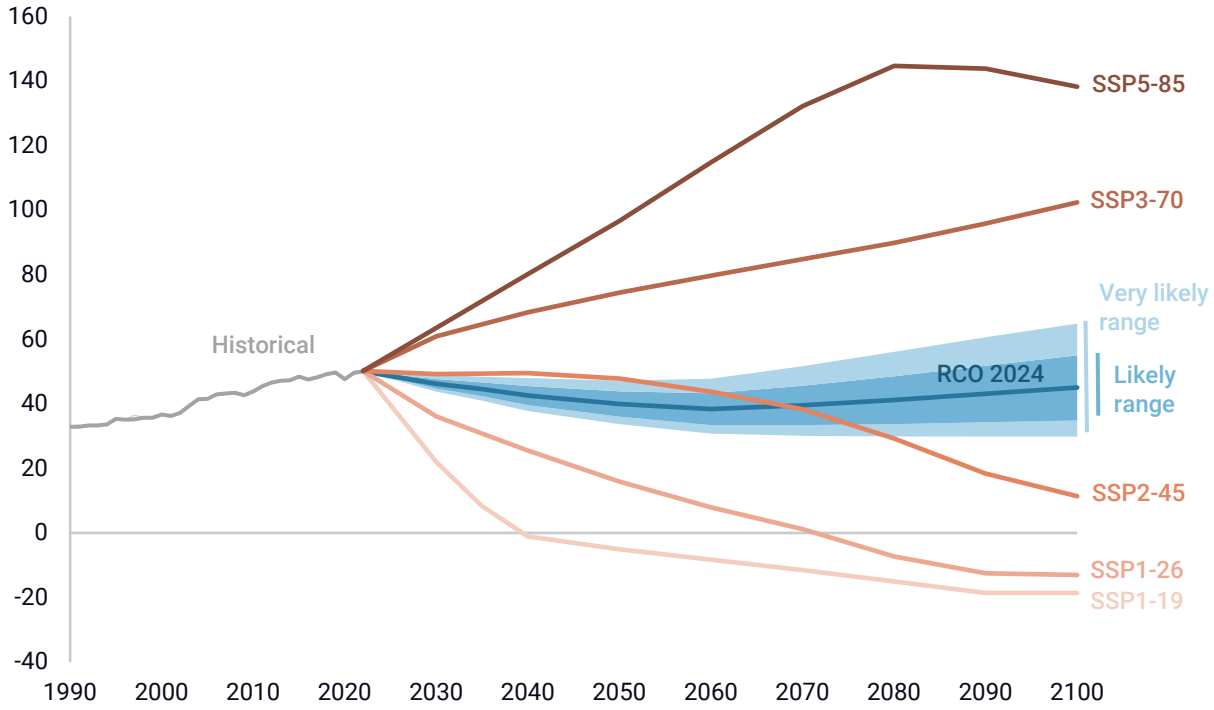


Source: Rhodium Climate Outlook. Following IPCC conventions, this report uses *very likely* to indicate a 90% probability of occurring and *likely* to indicate a 67% probability.

Even incorporating a wide range of potential socioeconomic, fossil fuel price, clean energy technology cost, and climate policy futures, the RCO Baseline range is much narrower than the range of emission projections used by global climate modelers to simulate future changes in temperature, precipitation, and other climate variables. These emissions projections, known as 'Shared Socioeconomic Pathways," each map out a stylized potential global future.[3] In the highest, SSP5-85, global GHG emissions grow from 50 gigatons CO_2e today to a peak of 145 gigatons in 2080, nearly 2.6 times higher than the highest emissions point in our *very likely* range that year (Figure 2). At the lower end, SSP1-19, global net GHG emissions fall to -18.6 gigatons by the end of the century, 48.5 gigatons lower than the bottom of our *very likely* range that year.

[3] For the sixth round of the Coupled Model Intercomparison Project (CMIP6) used to inform the IPCC's Sixth Assessment Report, global climate modelers were provided with "marker" emissions scenarios developed by the Integrated Assessment Modeling Consortium (IAMC). These emissions scenarios are shown in Figure 2.

FIGURE 2
Global GHG emissions scenario comparison
Billion metric tons of CO_2e, 100-year GWP, national inventory basis



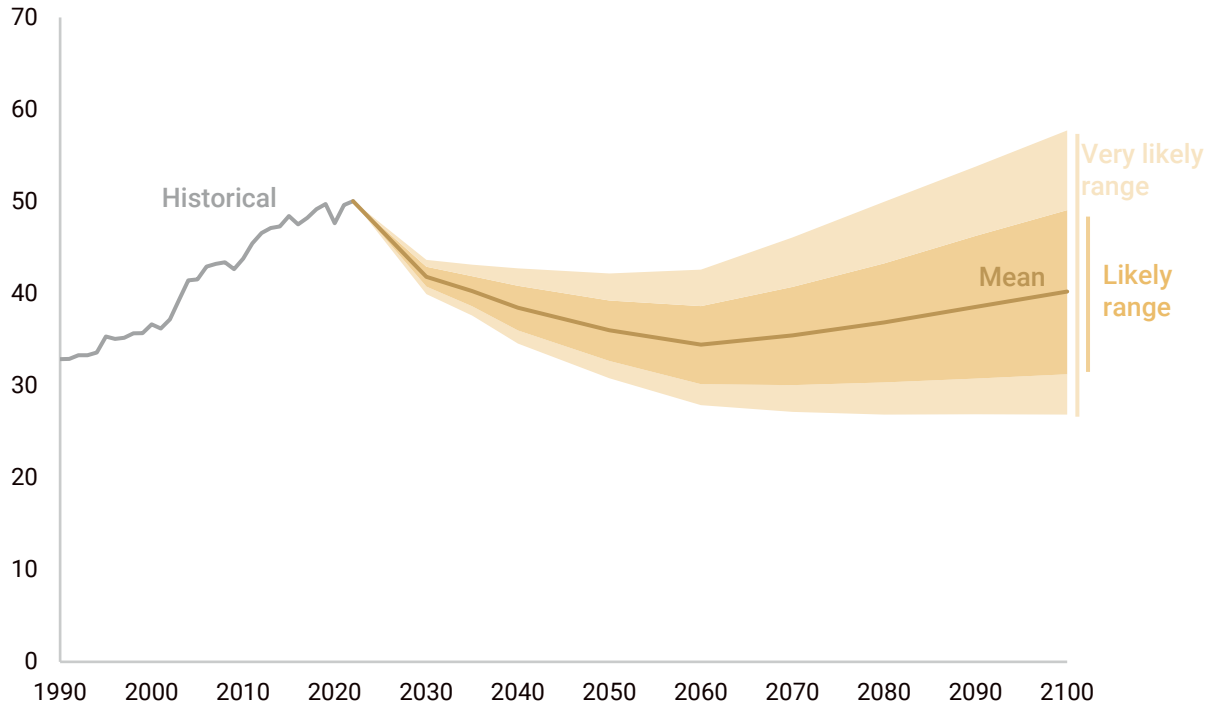
Source: Rhodium Climate Outlook, IIASA SSP Database. SSP emissions are adjusted to match national inventory reported emissions, for comparability with Rhodium Group's historical and projected emissions.

CURRENT NDC SCENARIO

If countries meet their current 2030 NDCs but do not accelerate action above and beyond their current trajectory in subsequent NDCs, we find that global emissions likely reach 41-43 gigatons by 2030, a reduction of 14-18% below 2019 levels (Figure 3). With 2030 NDCs constraints in place, uncertainty in the outlook for global GHG emissions is constrained only marginally through 2030, reducing the likely range of emissions from 45-48 gigatons under our RCO Baseline to 41-43 gigatons.

Without additional NDCs in place beyond 2030, however, uncertainty about the pace of decarbonization grows in the following decades. Progress slows considerably through 2050, delivering emission reductions of only 21-34% below 2019 levels by 2050, absent a new round of more ambitious NDCs in 2035 and beyond. In this scenario, global emissions *likely* reverse course and begin to grow after 2060, rising back up to an average of 40 gigatons (31-49 likely range) by century's end.

FIGURE 3
Current NDC Scenario: Global greenhouse gas emissions
Net emissions including removals (billion metric tons of CO_2-equivalent)



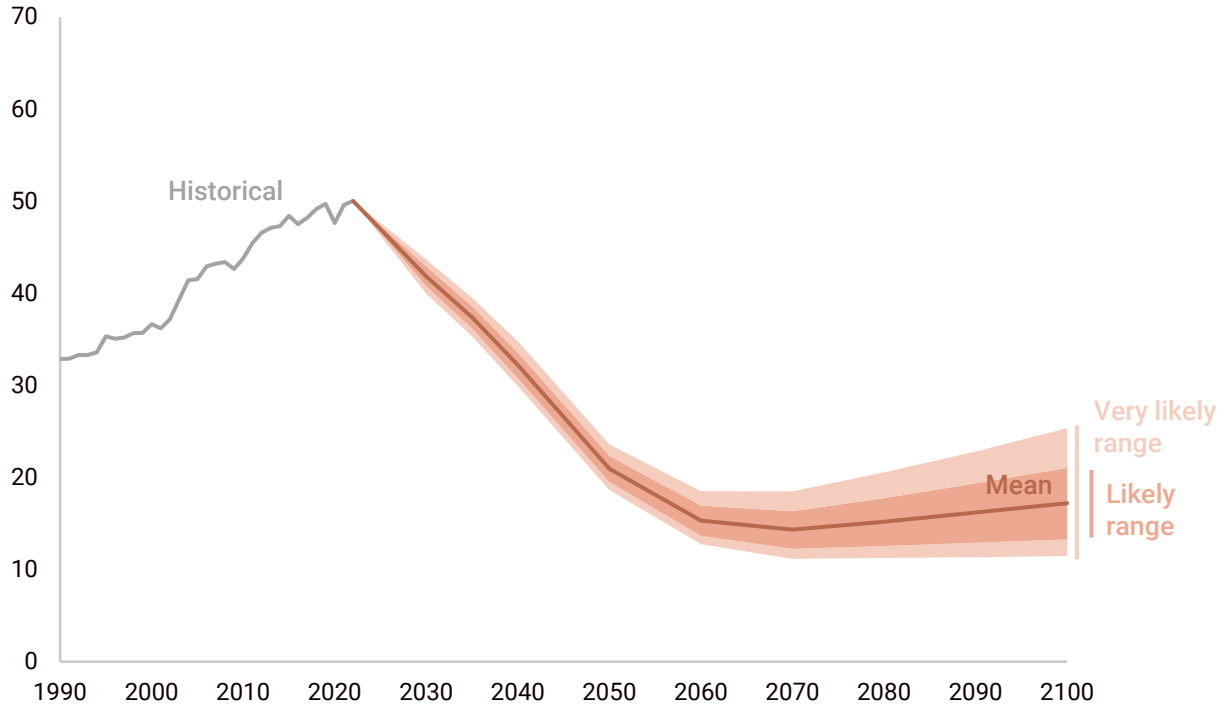
Source: Rhodium Climate Outlook. The Current NDC Scenario explores a future in which countries all meet their unconditional NDCs by 2030, but countries' post-2030 levels of climate policy ambition largely follow the path they are on today. Following IPCC conventions, this report uses *very likely* to indicate a 90% probability of occurring and *likely* to indicate a 67% probability.

CURRENT MID-CENTURY COMMITMENTS SCENARIO

This story changes dramatically if countries meet their current 2030 NDCs and set new 2035 and subsequent NDCs that keep them on a straight-line path to their stated targets of net-zero emissions or carbon neutrality by mid-century. Emissions follow the same path as the Current NDC scenario through 2030, but then diverge significantly in subsequent decades as countries maintain a steady pace of emission reductions through 2050 (Figure 4). Under our Current Mid-Century Commitment Scenario, global emissions *likely* drop to 36-38 gigatons (23-28% below 2019 levels) by 2035 and 18-21 gigatons by 2050 (58-63% below 2019 levels). Uncertainty in the outlook for emissions is constrained considerably if all countries follow a straight-line path from their 2030 NDCs to their existing mid-century goals, limiting the range of *likely* emissions in 2050 to a spread of only 2.6 gigatons compared to 6.6 gigatons under the Current NDC scenario (Figure 5).

Global emission reductions bottom out by 2070, leaving a residual of 12 gigatons of CO_2e on average (*likely* range of 10-14 gigatons). The remaining emissions represent those from countries that have not yet adopted mid-century net-zero targets as they continue to follow their RCO Baseline trajectories through century's end. In addition, countries with CO_2-only mid-century targets (i.e., China and Saudi Arabia) continue to emit non-CO_2 greenhouse gases at their baseline rate. Absent new or updated net-zero commitments, global emissions *likely* plateau at 11-18 gigatons through century's end.

FIGURE 4
Current Mid-Century Commitments Scenario: Global greenhouse gas emissions
Net emissions including removals (billion metric tons of CO_2-equivalent)



Source: Rhodium Climate Outlook. The Current Mid-Century Commitments Scenario illustrates the outlook for global emissions and temperature if all countries meet their 2030 NDCs and all countries achieve emission reductions consistent with a straight-line path to their current nationally-determined targets of net-zero emissions or carbon neutrality by mid-century. Following IPCC conventions, this report uses *very likely* to indicate a 90% probability of occurring and *likely* to indicate a 67% probability.

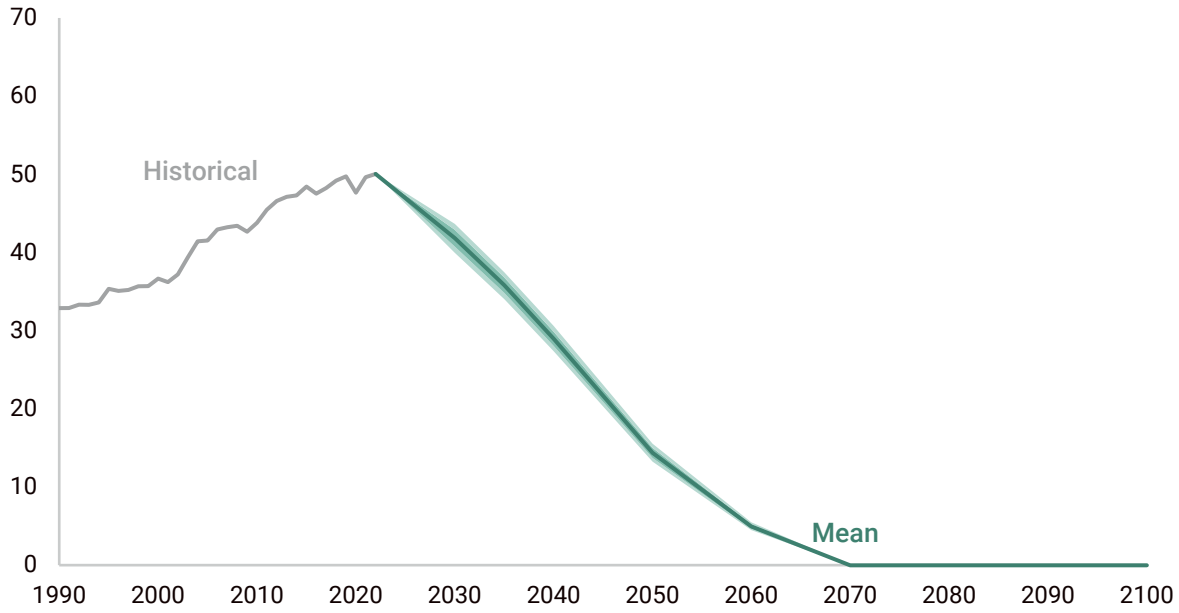
EXPANDED NET-ZERO COMMITMENTS SCENARIO

In our **Expanded Net-Zero Commitments Scenario**, countries with carbon-only neutrality commitments by mid-century expand to include all greenhouse gases, and countries without mid-century net-zero targets today decline to net-zero emissions by 2070. Under this scenario, global emissions *likely* drop to 35-37 gigatons by 2035 (26-30% below 2019 levels). By 2050, residual emissions of 13-15 gigatons *likely* remain (a drop of 70-74% below 2019 levels), but that declines to around 5 gigatons by 2060 and to zero by 2070 (Figure 5).

FIGURE 5

Expanded Net-Zero Commitments Scenario: Global greenhouse gas emissions

Net emissions including removals (billion metric tons of CO_2-equivalent)

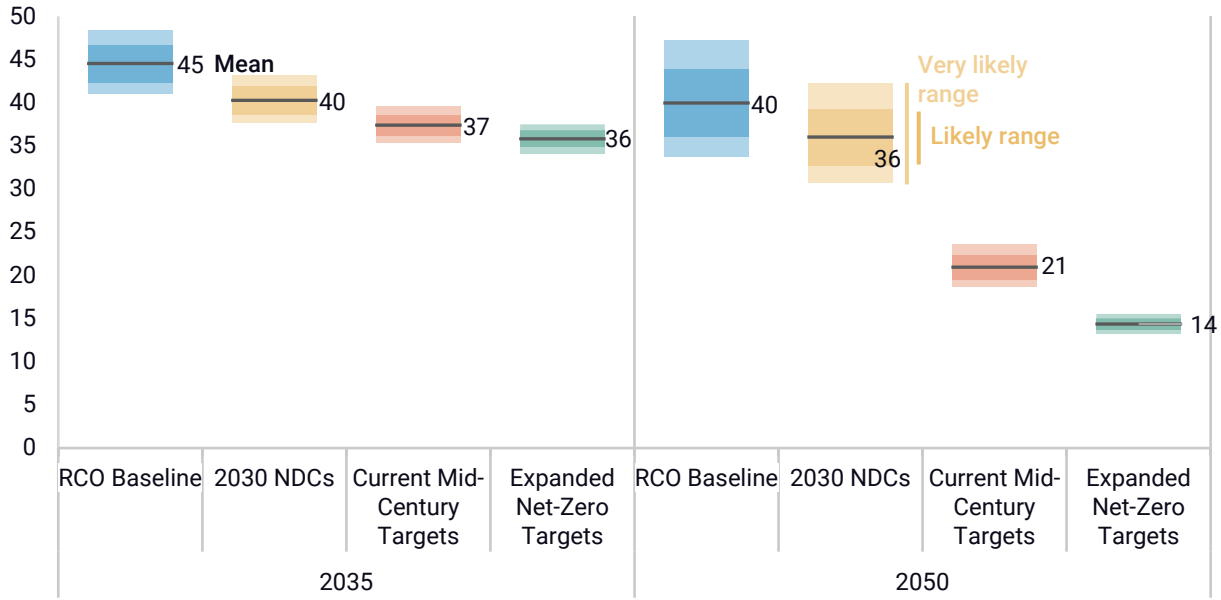


Source: Rhodium Climate Outlook. The Expanded Net-Zero Commitments Scenario adds 2070 net-zero emissions commitments for all remaining countries that don't currently have announced commitments, and expands commitments by those countries that have only set carbon neutrality commitments to cover all greenhouse gases.

FIGURE 6

Global GHG emissions under four scenarios

Net emissions including removals (billion metric tons of CO_2-equivalent) in 2035 and 2050



Source: Rhodium Climate Outlook

Global mean temperature rise outlook

To understand the global temperature rise implications of our four scenarios, we translate emissions trajectories into probabilistic global mean temperature rise projections using the Finite-amplitude Impulse Response (FaIR) model (see the Technical Appendix for more detail).

RCO BASELINE

In our RCO Baseline scenario, we find that across our range of emission outcomes, the world is *very likely* on track for an increase in global mean surface temperature of 2.0-3.7°C and *likely* on track for 2.2-3.2°C by century's end (Figure 7). The mean projection across our uncertainty range is 2.7°C above pre-industrial levels. Given the current outlook for the key drivers of emissions, we find there is a less than 7% chance of keeping global temperature increases below 2°C, the Paris Agreement goal, absent an acceleration in the pace of climate policy ambition or technological innovation.

While the RCO temperature outlook marks a considerable improvement relative to projections from the IPCC Fifth Assessment Report or the higher emissions scenarios used by global climate modelers, it is also clear the world is not on track to meet the Paris Agreement's global temperature targets.

CURRENT NDC SCENARIO

Under the Current NDC scenario, we find that the world is *very likely* on track for an increase in global mean surface temperature of 1.8-3.5°C and *likely* on track for 2.1-3.0°C by century's end (Figure 7). The mean projection across our uncertainty range is 2.6°C above pre-industrial levels. In a world in which countries continue the level of ambition consistent with 2030 NDCs, we find there is a less than 12% chance of keeping global temperature increases below 2°C absent an acceleration in the pace of climate policy ambition or technological innovation.

CURRENT MID-CENTURY COMMITMENTS SCENARIO

The outlook changes considerably in a world in which countries accelerate their ambition in 2035 and beyond to stay on a path to reach the mid-century net-zero and carbon neutrality targets that countries already have in place. Under the Current Mid-Century Commitments Scenario, we find that the world is *very likely* on track to see an increase in global mean surface temperature of 1.3-2.5°C and is *likely* on track for 1.5-2.2°C by century's end (Figure 7). The mean projection across our uncertainty range is 1.8°C above pre-industrial levels. If countries meet their current mid-century commitments, the odds of keeping temperature rise below 2°C increase to 68% and, for the first time, keeping temperature rise below 1.5°C becomes a possibility, however remote (less than a 12% chance).

EXPANDED NET-ZERO COMMITMENTS SCENARIO

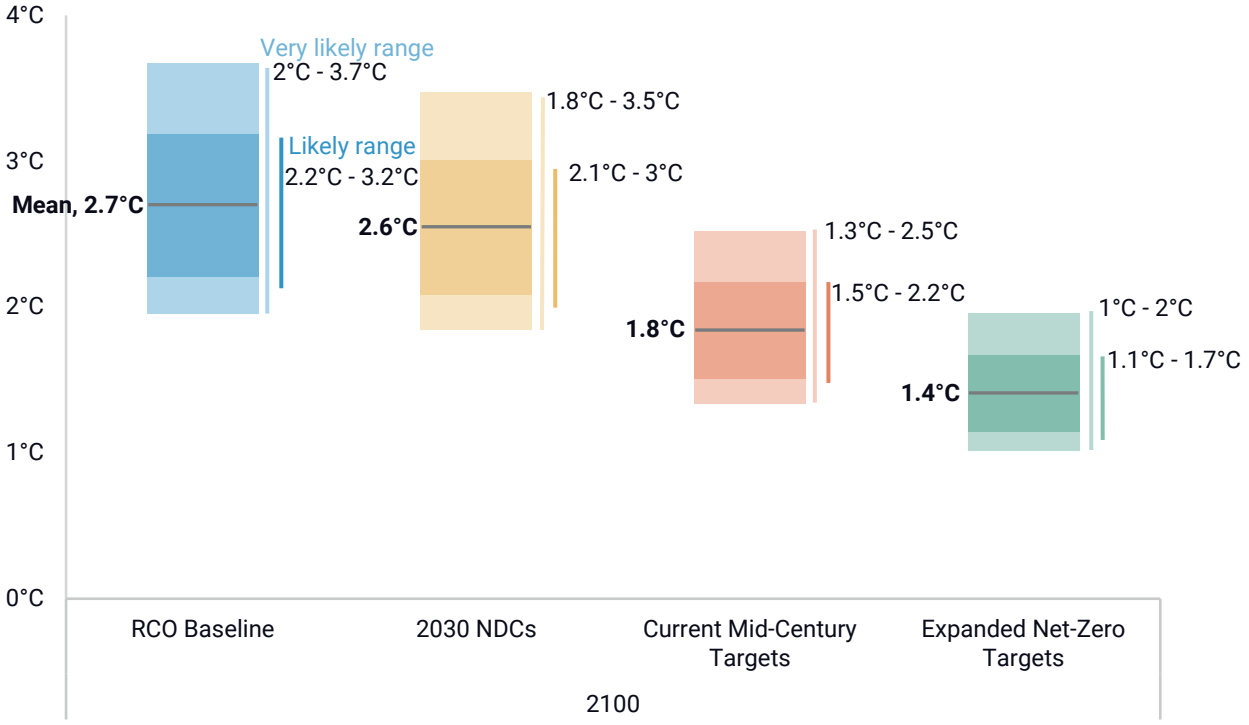
Getting all countries to net-zero emissions by 2070 pushes up the odds of end-of-century global mean temperatures below 2°C to 96%. The chances of temperatures ending the century below 1.5°C by also rise substantially, nearing 62%, though with a mid-century overshoot of 1.5°C. Under the Expanded Net-Zero Commitments Scenario, we find that

the world is *very likely* on track to see an increase in global mean surface temperature of 1.0-2.0°C and is *likely* on track for 1.1-1.7°C at century's end (1.4°C on average) (Figure 7). This is a reduction from a temperature peak in 2050, with a *very likely* range of 1.3-2.2°C, a *likely* range of 1.5-2.0°C and a mean estimate of 1.7 °C.

FIGURE 7

Global mean temperature rise

Degrees Celsius above pre-industrial temperatures



Source: Rhodium Climate Outlook

The chapter that follows digs into the sector-level and regional emissions trends in our RCO Baseline scenario and identifies areas where more policy and innovation are required to move closer to a global emissions pathway consistent with keeping global mean temperature rise well below 2°C.

CHAPTER 3

Going Deeper: Regional and Sectoral Outlook

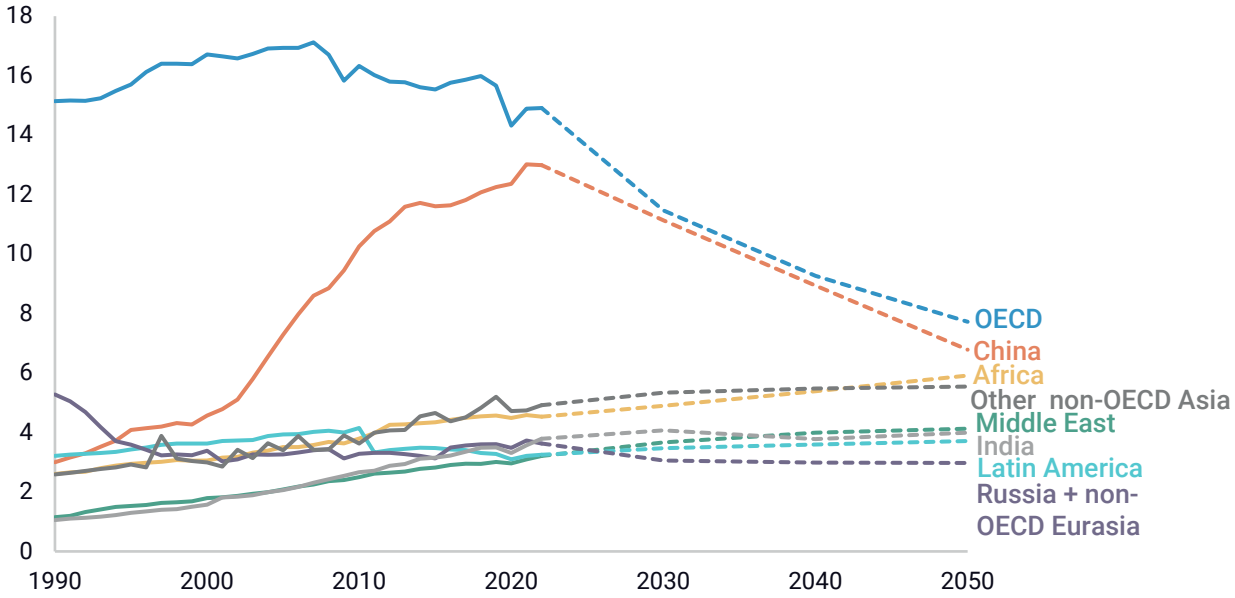
To accurately assess what's required at a policy and technology level to move from our current RCO Baseline towards global net-zero emissions around mid-century, it is important to understand what is driving the energy and emissions dynamics today. Digging into the underlying sources of emissions in our RCO Baseline can shed light on where the world is already making meaningful progress and where more policy, investment, and innovation are needed.

The developed world—here defined as members of the Organization for Economic Cooperation and Development (OECD)—accounted for the majority of global emissions growth during the 20th century. Since 2000 that has shifted, with China accounting for more than half of the growth in emissions globally. Emissions from India and other non-OECD economies have risen as well, though not at the pace as in China (Figure 8). Going forward, we expect that to change considerably. China's emissions have *very likely* already peaked and begun what we project will be a long, secular decline due to structural economic changes, falling population, and rapid expansion of clean energy technologies.

FIGURE 8

Mean global emissions by region

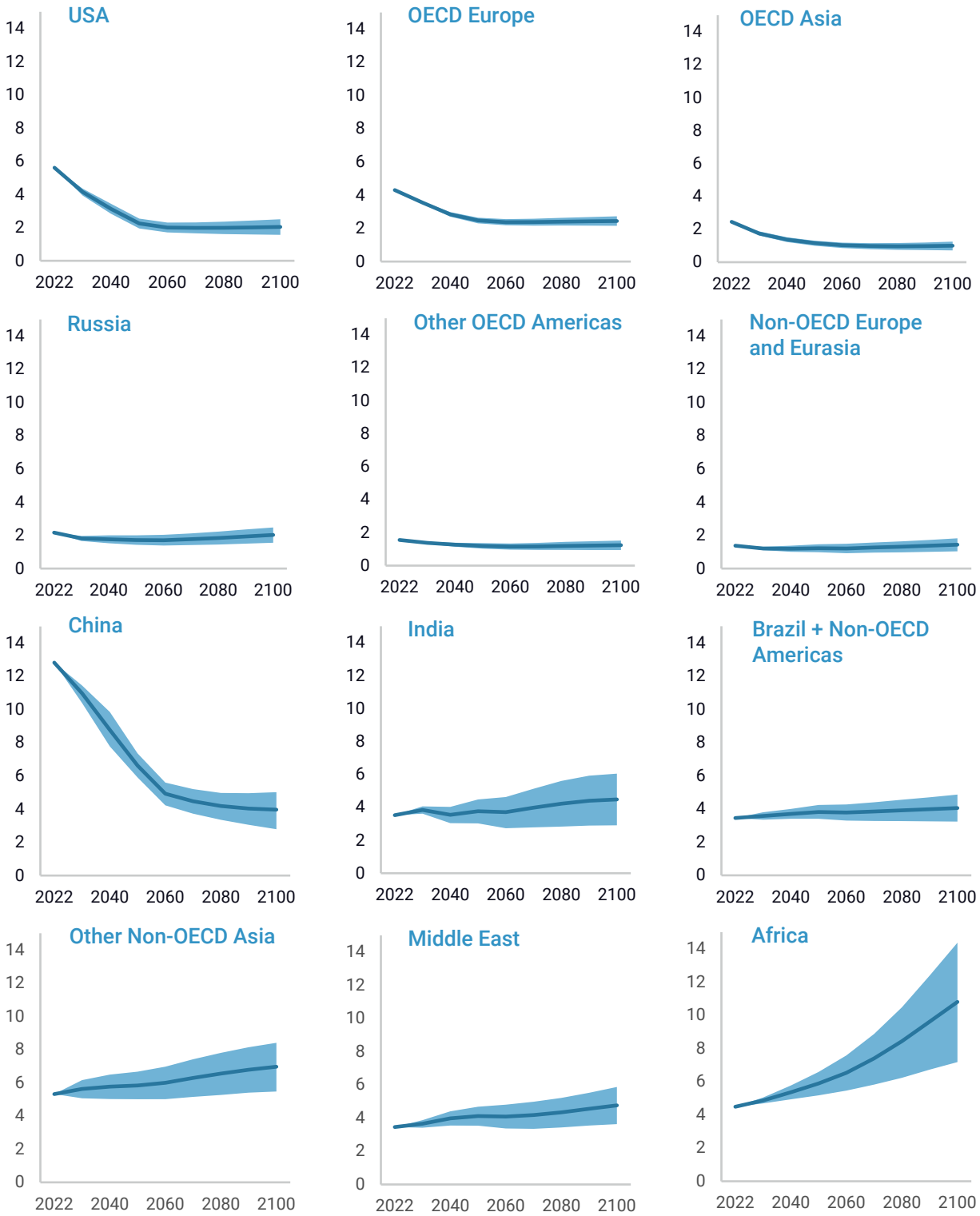
Net emissions including removals (billion metric tons of CO_2)



Source: Rhodium Climate Outlook

Emissions from OECD countries decline as well as a result of significant decarbonization investment and clean energy policy. The bulk of emissions growth in the decades ahead comes from Africa, the Middle East, India, and other non-OECD countries in Asia, driven predominantly by economic growth as these regions continue to develop (Figure 9). To see continued global progress toward net-zero emissions by around mid-century, levels of decarbonization progress similar to what we have seen in OECD countries and China—including increased access to investment and innovation—will be required across all regions.

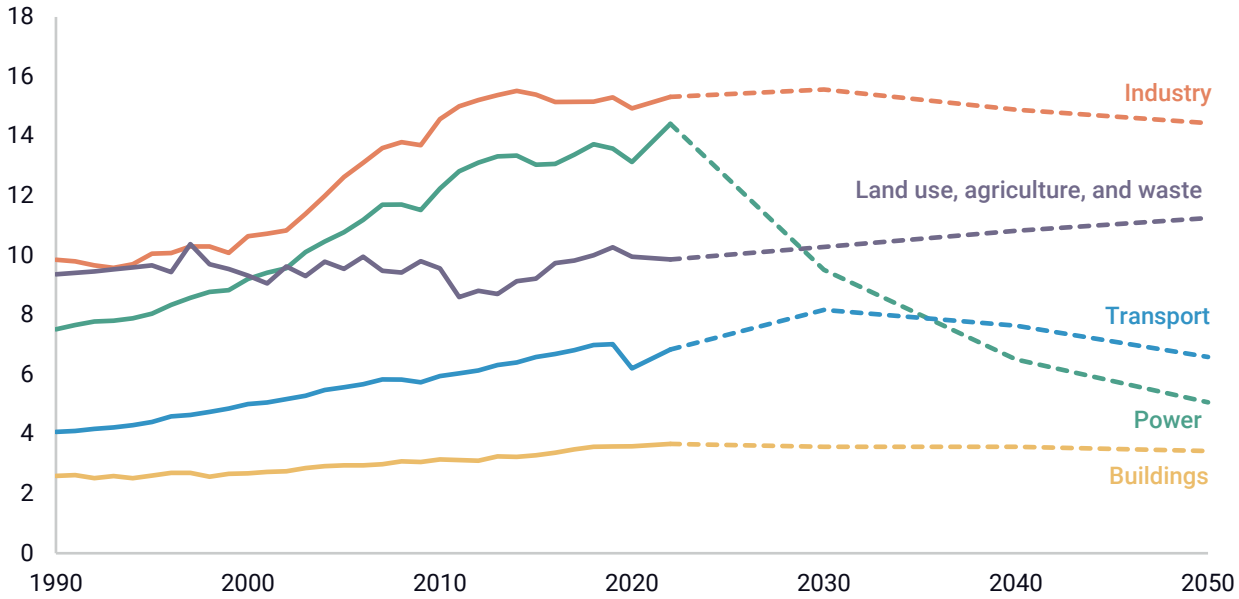
FIGURE 9
GHG emissions by region
Million tons of CO_2e, *likely* range (67% chance)



Source: Rhodium Climate Outlook

In our RCO Baseline, we expect a significant change in the sector-level composition of emissions as well. Global emissions from the power sector accelerated sharply in recent decades, nearly doubling between 1990 and today. Looking ahead, however, we expect this to change as more than two decades of policy and innovation focused on electricity decarbonization drive clean electricity technology deployment at scale (Figure 10). As a result, in the RCO Baseline it is *likely* that global emissions from the power sector have peaked and will decline rapidly in the coming decade.

FIGURE 10
Global GHG emissions by sector
Net emissions including removals (billion metric tons of CO_2), projection mean

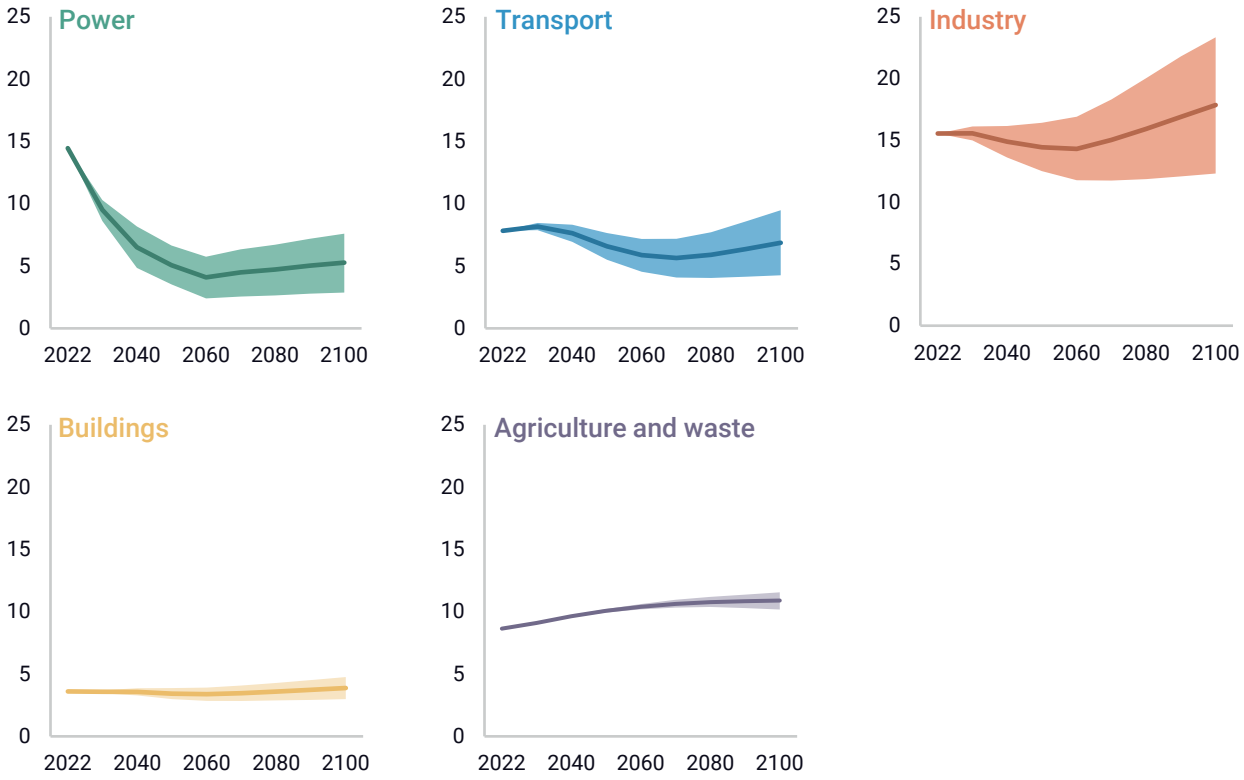


Source: Rhodium Climate Outlook

Decarbonization progress in the transportation sector is also gaining steam. After a sharp rise in emissions from transportation in recent years—growing 69% since 1990—we expect that trend will *likely* reverse by the end of this decade as vehicle electrification accelerates. Similarly, emissions from the buildings sector *likely* decline through mid-century—thanks in large part to a steep reduction in HFCs used in air conditioning and refrigeration driven by implementation of the Kigali Amendment to the Montreal Protocol, as well as electrification of heating and modest efficiency improvements.

However, policy and technology progress has been slower in the industrial sector, which includes production of iron, steel, cement, oil and gas, and chemicals. A diverse and challenging sector to decarbonize, there's a 24% chance that emissions from industry rise over the coming decades in the RCO Baseline as demand for industrial products grows. While the three highest-emitting industries today—oil and gas, iron and steel, and cement production—*likely* see emissions reductions through mid-century, deeper cuts are limited by a lack of policy and widely-available and affordable clean technologies and fuels. More than other sectors, the outlook for industry is also extremely uncertain, with demand for industrial products closely tied to the overall outlook for economic and population growth. Similarly, emissions from agriculture and waste are expected to rise gradually over the next few decades, where they *likely* slow or gradually decline.

FIGURE 11
Range of *likely* global emissions for key sectors
Billion tons of CO_2e, *likely* range (67% probability of occurring)



Source: Rhodium Climate Outlook

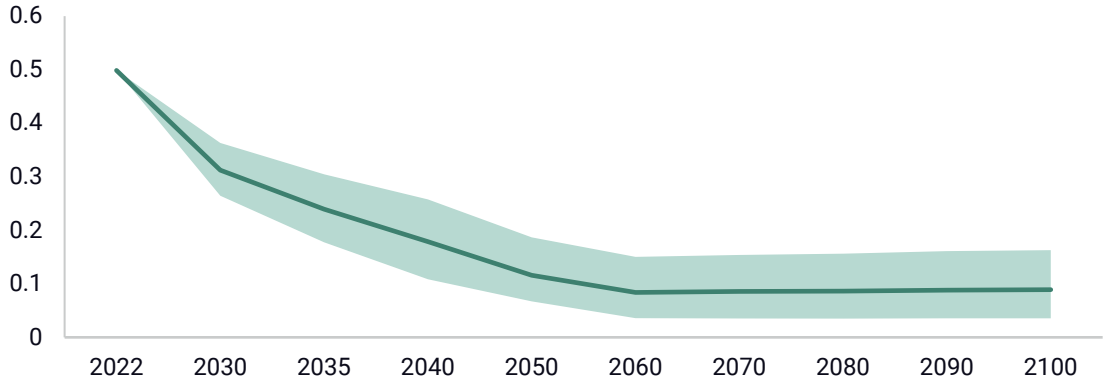
In the rest of this chapter, we dive deeper into the dynamics playing out in these key sectors under our RCO Baseline, as well as the underpinning regional dynamics.

Electric power

The electric power sector is today's second-largest source of emissions globally at 28%, emitting 14.4 gigatons of CO_2e in 2022. However the electric power sector has also made the most significant strides in scaling decarbonization solutions globally. This progress stems from a combination of policies targeting power sector emissions and declining costs of solar and wind technologies, leading to exponential growth in renewable deployment over the past decade. These trends are expected to continue, ensuring a steady reduction in the emissions intensity of electric power in the coming decades.

Our RCO Baseline projections show a very high likelihood (greater than 90% probability) that the emissions intensity of power generation will continue to improve significantly through 2060, assuming climate policy ambition maintains its historical pace (Figure 12). The scale-up of renewable energy that fuels this rapid decline in emissions intensity is remarkable. We find variable renewable energy (VRE) generation from solar and wind likely reaches six to nine times today's levels by 2050.

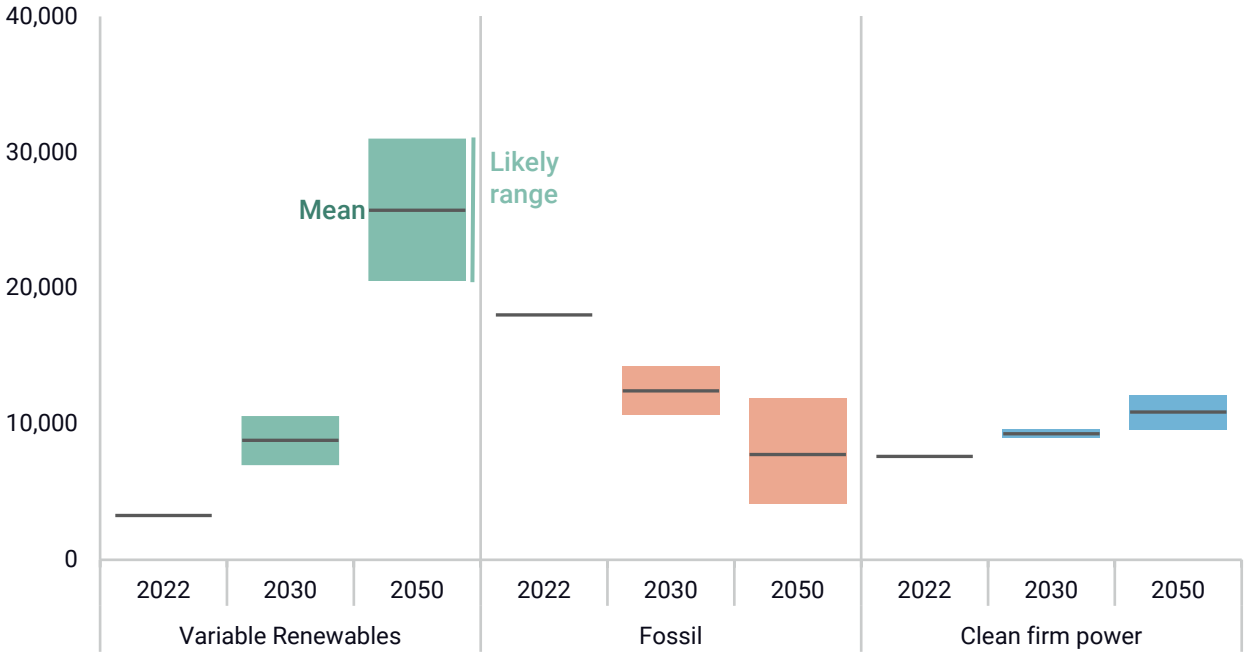
FIGURE 12
Emissions intensity of global electric power
Million metric tons of CO_2e per Terawatt hour (TWh), very likely range (90% probability)



Source: Rhodium Climate Outlook

Driving this growth in renewable energy is an increase in electricity demand, including through electrification of transportation and other end uses, as well as supportive clean energy policies and the continuing decline in renewable technology costs. By 2050, power demand *likely* increases by 18-76% from today's levels, with new power uses—including electric vehicles and clean hydrogen production—accounting for nearly 80% of the increased demand on average. Over the same period, fossil generation falls 34-77%, as low-cost renewables out-compete fossil to meet demand. Clean firm power generation is projected to grow by 25-59% by 2050 compared to current levels to complement the expansion of variable renewable energy and ensure grid reliability.

FIGURE 13
Global electric power generation by source
Terawatt hours (TWh), *likely* range (67% chance)



Source: Rhodium Climate Outlook. Bars indicate *likely* range, line indicates projected mean.

REGIONAL DYNAMICS IN THE POWER SECTOR

Our findings reveal stark differences in the transition to clean electricity between two major groups of countries: OECD economies and China on the one hand, and the rest of the world on the other. OECD countries and China are driving the majority of variable renewable expansion in absolute terms. Their VRE generation *likely* increases by a factor of 6-8 between 2022 and 2050. While the rest of the world also sees significant VRE generation growth, *likely* increasing by 11-13 times in the same period, it starts from a much lower base. By 2050, countries outside of the OECD and China *likely* account for only 20-25% of global VRE generation, despite accounting for around 30% of global power demand on average (Figure 14).

At the same time, fossil fuel-based generation in OECD countries and China *likely* decreases to between one-seventh and one-third of its current levels by 2050. In the rest of the world, where policy ambition and clean energy investment has generally been lower, future reliance on fossil fuels is highly tied to economic growth and therefore less certain, with projections showing potential for either significant decline or modest growth by 2050.

While absolute generation figures (in terawatt-hours) provide valuable insights, examining the relative shares of different energy sources reveals an even starker picture of regional disparities. In OECD countries and China, variable renewables are expected to dominate the electricity mix by 2050, growing on average to nearly two-thirds of total generation, bringing the total share of clean electricity to 91% (Figure 15). In contrast, the transition is slower in other regions, with variable renewables increasing on average to about 40% by 2050, bringing the share of clean electricity to 62% on average. Concurrently, fossil fuels' average share in electricity generation is projected to fall dramatically in OECD countries and China, from over 50% to less than 10%, while in other regions it declines from about 75% to 38%.

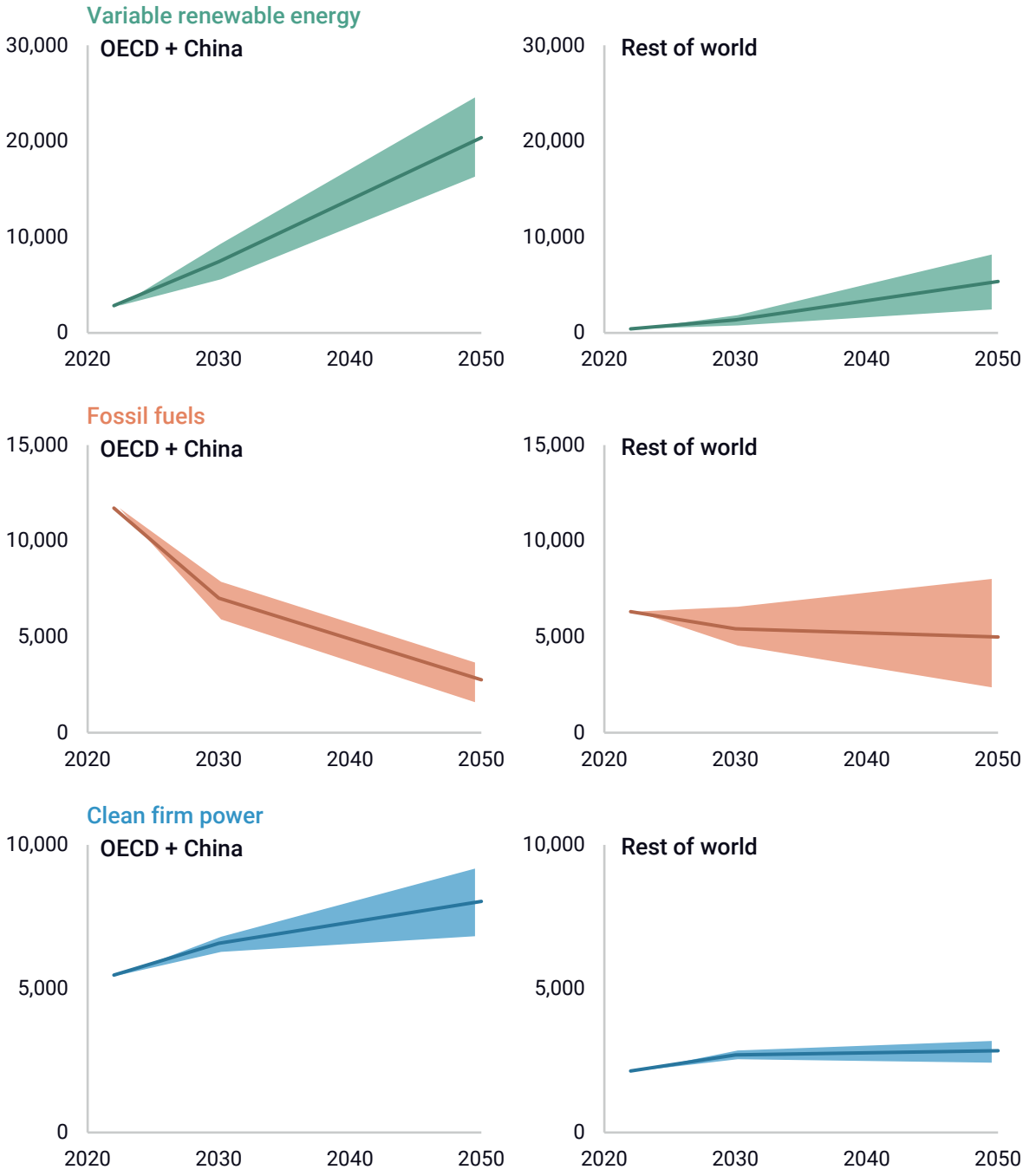
While variable renewable energy sources are projected to dominate electricity generation by mid-century in OECD countries and China, this alone is insufficient for complete power sector decarbonization. Renewable deployment needs to be accelerated in the rest of the world, where much of the demand growth post-2050 occurs. Even in advanced economies, clean firm power sources—including utility-scale batteries, advanced geothermal, and next-generation nuclear—are crucial to reducing reliance on fossil fuels that remain online to complement VRE and ensure grid stability.

Clean firm power sources are projected to grow by 25-68% between today and 2050. Utility short-duration batteries (4-to-8-hour duration) play a major role in balancing the power grid in these regions, helping to integrate renewable energy effectively. Starting from 44 GW in 2022, the installed capacity of short-duration batteries is projected to grow significantly, reaching between 440 and 1,260 GW globally in our *likely* range, with more than 95% of this capacity deployed in OECD countries and China on average.

FIGURE 14

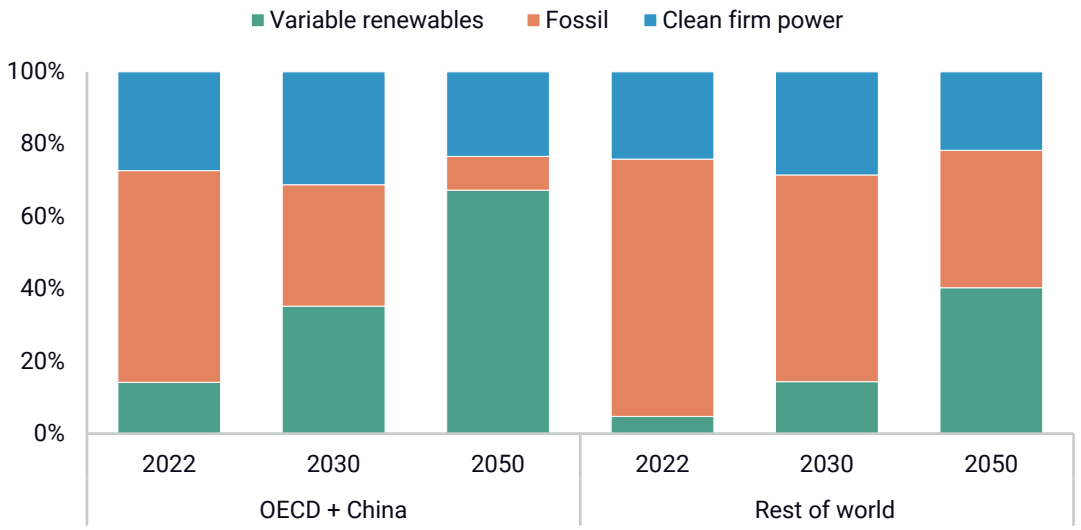
Electricity generation from variable renewable energy (green), fossil fuels (orange), and clean firm power (blue)

Terawatt hours (TWh), mean projection and *likely* range (67% chance)



Source: Rhodium Climate Outlook. Fans indicate *likely* range; line indicates projected mean.

FIGURE 15
Electricity generation shares in OECD countries + China, and rest of the world
Percent share of total electricity generation, mean projection



Source: Rhodium Climate Outlook

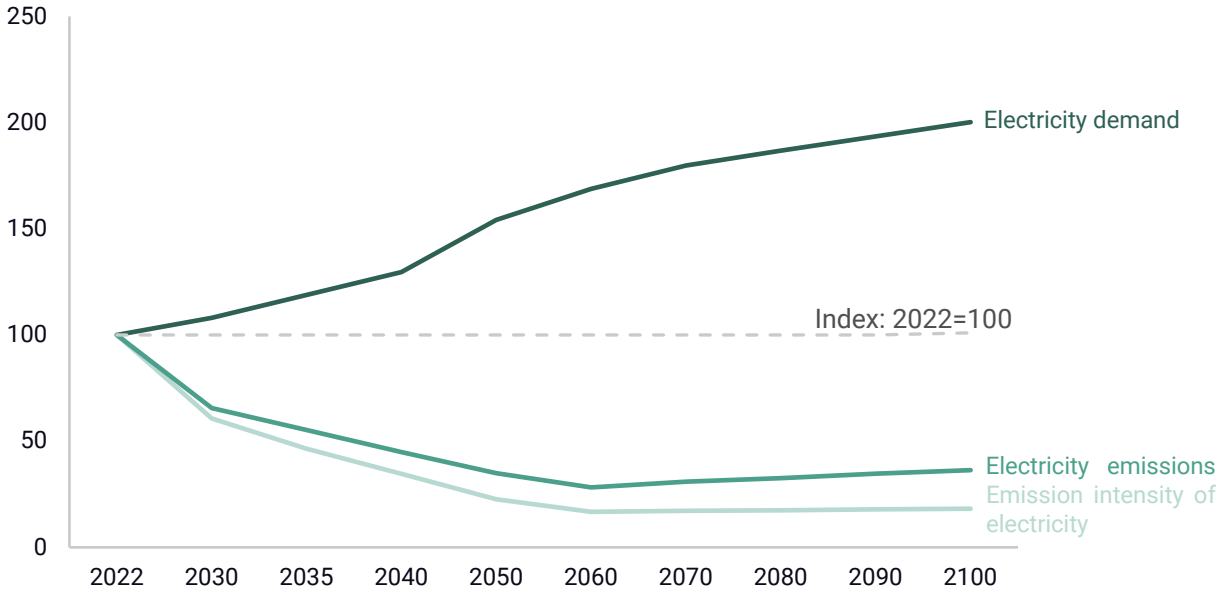
CLEAN ENERGY DISPARITY IN EMERGING ECONOMIES SLOWS DOWN EMISSIONS PROGRESS

While clean energy investment is rising rapidly in advanced economies, it remains far below what's needed in emerging and developing economies. This disparity in clean energy adoption is largely due to differences in policy support, access to finance, and availability of supporting electric infrastructure. Many emerging economies face unique challenges, including higher perceived investment risks and less developed capital markets, which hinder their ability to rapidly scale up renewable energy deployment.

Advanced economies, despite their faster progress, also face significant hurdles in their clean energy transition. These include long interconnection queues, protracted permitting processes, and challenges in transmission expansion and facility siting. While potentially less constraining than barriers in developing regions, these issues still impact short-term renewable energy deployment. Addressing these challenges is crucial for maintaining the momentum of clean energy transitions in these countries.

The current lack of mature, cost-effective clean dispatchable options, combined with inadequate support for mature renewable technologies in fast-growing economies, contributes to a deceleration of power sector emission reductions after 2060 absent an acceleration of climate and clean energy policy and innovation. Indeed, we find that after significant progress in reducing the global emissions-intensity of electric power and overall power sector emissions through mid-century, decarbonization begins to plateau and even reverse slowly near century's end as global electric power demand continues to grow (Figure 16). To reach net-zero emissions across the global economy, emissions from electric power will need to zero out completely, and likely before mid-century to give room for other harder-to-abate sectors. Unless we accelerate policy ambition and innovation, power sector emissions will stubbornly persist, *likely* remaining between 2.8 and 7.6 gigatons of CO_2e through century's end.

FIGURE 16
Power decarbonization plateaus as demand growth offsets reductions in emissions intensity
Mean projections, index 2022=100



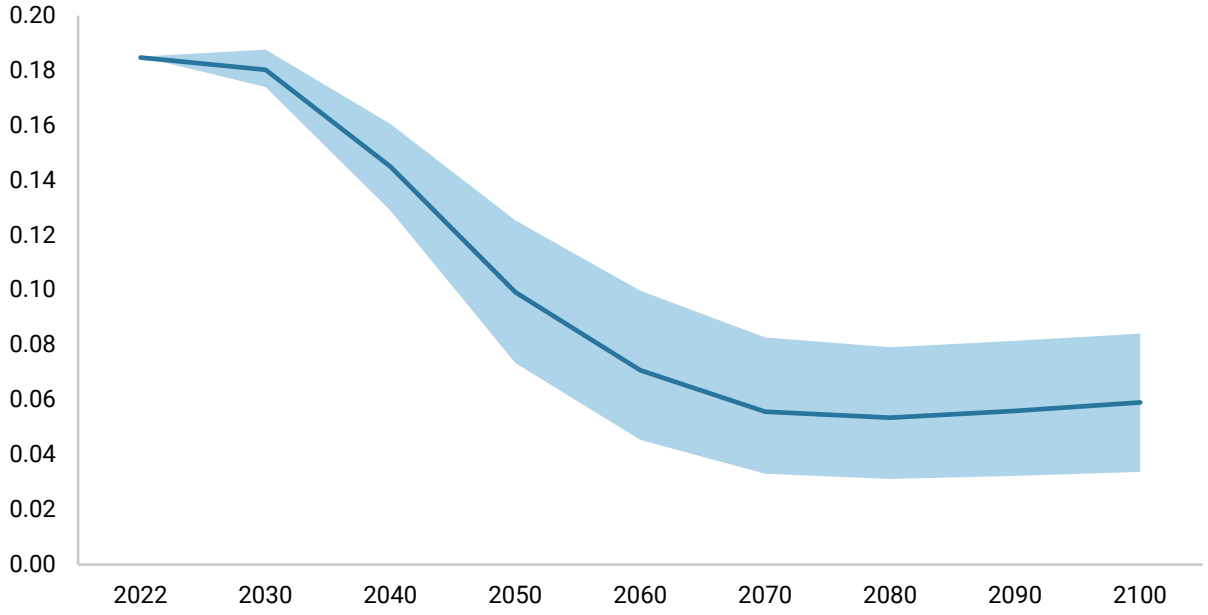
Source: Rhodium Climate Outlook

Transportation

Along with the power sector, the world is also making progress in reducing emissions from the transportation sector, which currently accounts for 15.6% of global emissions, emitting 7.9 gigatons of CO_2e in 2022. This progress is due in large part to the electrification of vehicles. One in five new cars globally will be electric this year, up from only one in twenty in 2020. Like wind and solar technologies, policy and scaled-up investment over the past decades have worked in tandem to drive down electric vehicle (EV) battery costs, bringing the relative costs of EVs down sufficiently to compete with internal combustion engines. EV battery prices are expected to continue to fall over the coming decades, which bodes well for their continued expansion. The same cost declines in battery technologies that have allowed passenger EVs to take off will also eventually help scale the EV market for medium- and heavy-duty trucks.

In fact, our modeling shows that considering a wide range of uncertainty in oil prices, charging infrastructure, and future policy ambition (among the other drivers of uncertainty we model), EVs will *very likely* make up at least half and as much as 80% of passenger vehicle sales globally by mid-century. Sales of electric medium and heavy-duty trucks *likely* reach 25-70% of all new vehicles in the same timeframe. This in turn drives down the emissions intensity of on-road vehicles (i.e., total GHGs emitted per mile of travel) through 2070 in our *very likely* range (Figure 17).

FIGURE 17
Emissions intensity of global passenger vehicles
GHGs (tons CO_2e) per mile, *very likely* range (90% chance)

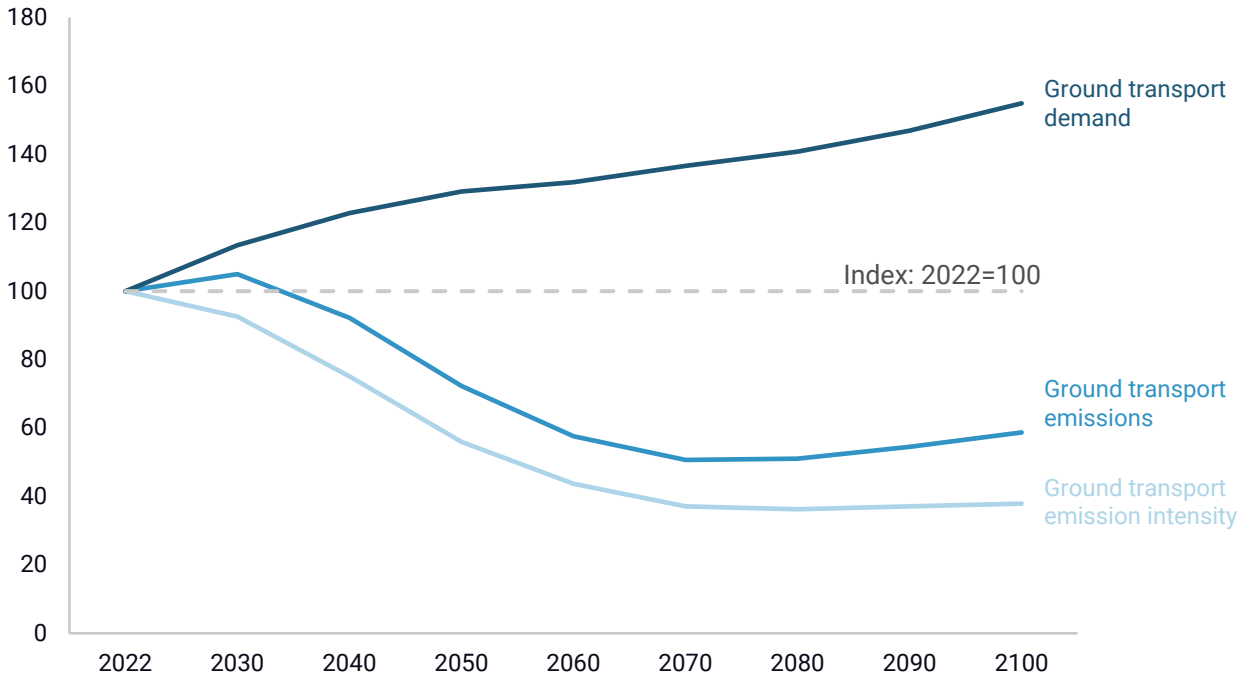


Source: Rhodium Climate Outlook

Mirroring what we see in the power sector, however, there is still a need for accelerated policy and technology cost reductions. While the rapid deployment of existing technologies helps decarbonize the majority of road transport, it doesn't decarbonize the last tranche of emissions. This is due in large part to an increase in global demand for transportation—including both passenger and freight—which rise significantly over the coming decades. By mid-century, that demand growth starts to outpace the gains from decarbonization of road vehicles. While OECD countries, China, and India see high levels of electrification, the remaining regions see limited electrification due to economics and infrastructure challenges. As a result, the emissions intensity of road vehicles plateaus through century's end absent an acceleration of policy and investment (Figure 18). Even with high levels of electrification, deployment barriers, including infrastructure challenges, remain through century's end absent an acceleration of policy and investment, making it difficult to decarbonize the last remaining share of road transport.

The other part of the challenge in decarbonizing transportation is that while we have increasingly mature decarbonization technologies for road transport, technologies and fuels to decarbonize aviation and shipping require further innovation and scale to bring down costs. These two modes of transportation *likely* see very rapid growth in demand (and emissions) over the coming decades (Figure 19). Marine and aviation emissions are currently only 21% of total transportation emissions, nearly four times smaller than emissions from road transport, but that is expected to change over time as the road sector decarbonizes.

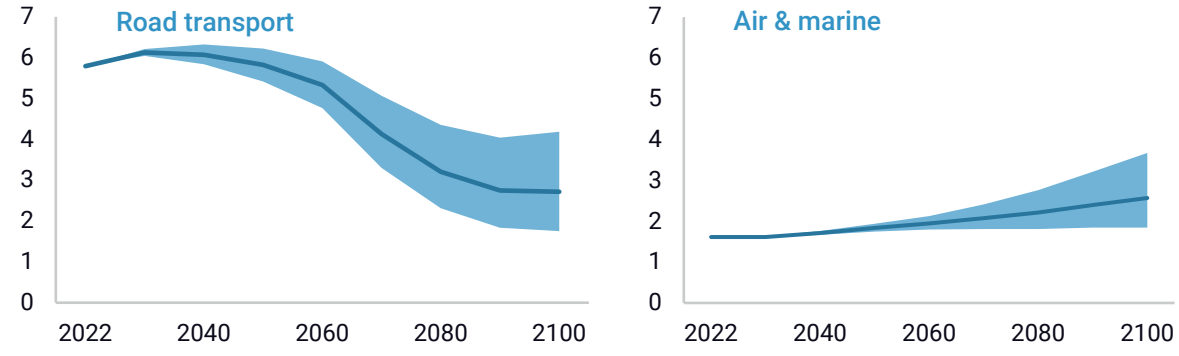
FIGURE 18
On-road vehicle decarbonization plateaus as growth in travel demand soars
Mean projections, index 2022=100



Source: Rhodium Climate Outlook

As policy and innovation drive decarbonization for passenger and freight vehicles, emissions from air and marine transport remain stubbornly high, despite a meaningful rise in deployment of low-emission sustainable aviation fuel (SAF) in the aviation sector. Absent an acceleration of climate policy and/or innovation in the marine and aviation sectors, those emissions are *likely* to account for a third of total transport emissions by mid-century, and grow as large as road transport levels by century's end as population and economic growth in many emerging markets drive transportation demand.

FIGURE 19
Global GHG emissions by transport mode
Million metric tons of CO_2e, *likely* range (67% chance)



Source: Rhodium Climate Outlook

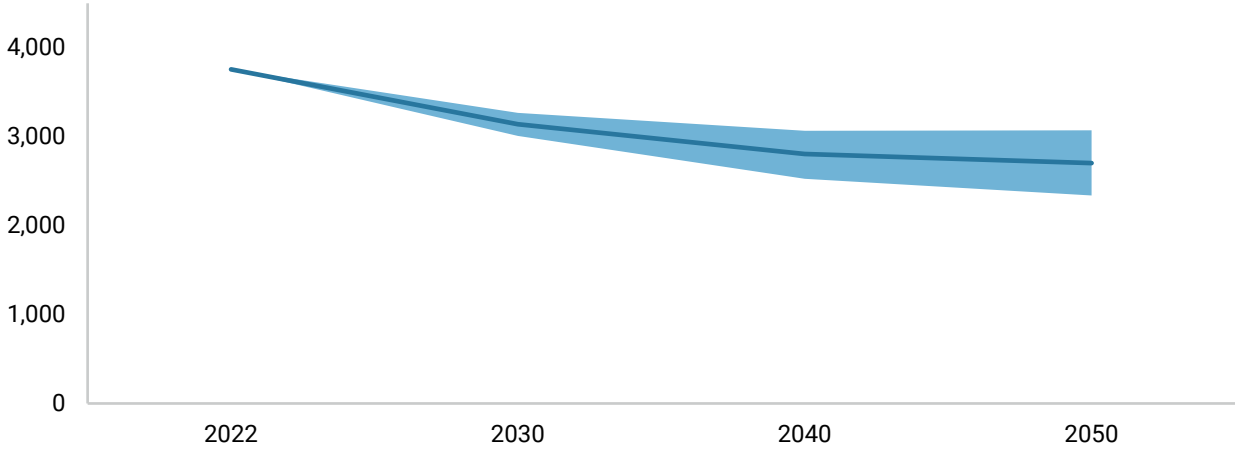
Industry

The industrial sector—including manufacturing, refining, and oil and gas processing—is today's single largest source of emissions globally at 31%, emitting 15.5 gigatons of CO_2e in 2022. With limited technology and policy progress to date, future emissions trends are primarily driven by economic development and population growth. As a result, our projection includes a wide range of potential outcomes, with emissions *likely* reaching 12.5 to 16.5 gigatons of CO_2e by 2050 and 12 to 23 gigatons by 2100. A diverse set of complex and often energy-intensive processes, industry faces unique challenges to decarbonization. The sector therefore *likely* remains the biggest source of emissions for decades to come. In fact, by 2050, industrial emissions equal all emissions from power, transportation, and buildings combined in our projection mean.

Today, industrial emissions are spread across a wide range of activities, including oil and gas production (28% of industrial emissions), cement and non-metallic minerals (19%), iron and steel (15%), chemicals (9%), refining (6%), among many others. Below we highlight how emissions from this diverse sector are likely to evolve over the coming decades.

Emissions from oil and gas production are the largest single source of industrial emissions. Fortunately, fugitive methane emissions, which make up more than 80% of the sector's emissions, can be addressed through cost-effective mitigation solutions that exist today. Regulation, including rules recently finalized in the US and EU, coupled with moderating natural gas and oil demand, *likely* drive down methane emissions from oil and gas production to 18-38% below today's levels by 2050 (Figure 20). In the absence of additional policy action, uncertainty in future oil and gas demand and prices leads to a wide range of potential emissions in the latter half of the century, with a more than 50% probability that emissions rebound by 2100. Recent pledges to significantly reduce the methane emissions-intensity of oil and gas—including the Global Methane Pledge—will go a long way to reduce the overall uncertainty in emissions from this sub-sector if implemented.

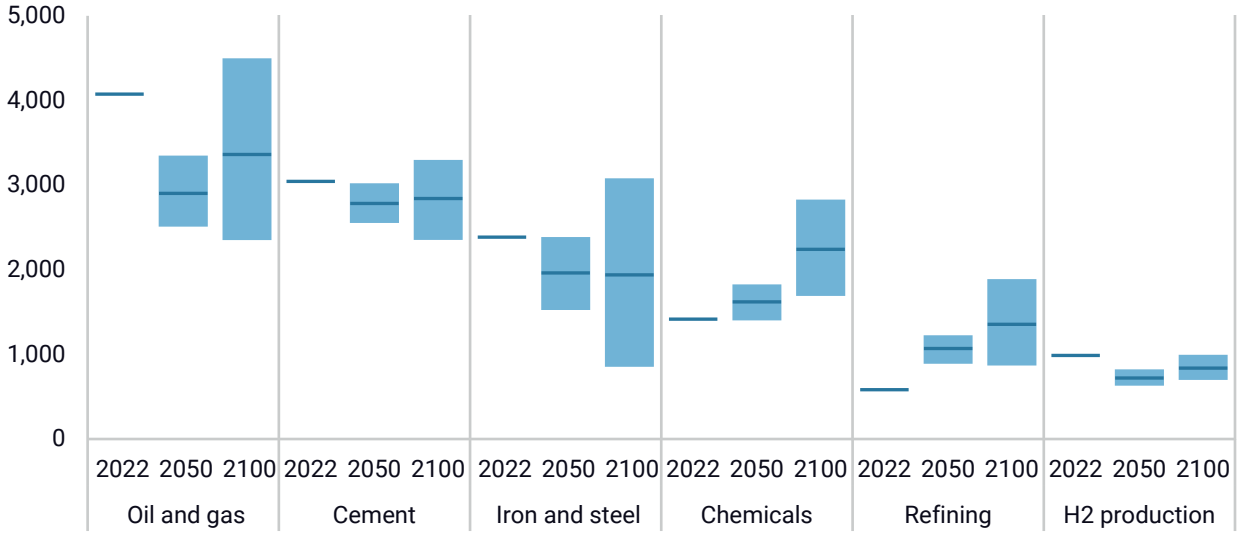
FIGURE 20
Oil and gas methane emissions
Million metric tons of CO_2e, *likely* range (67% chance)



Source: Rhodium Climate Outlook

Emissions from chemicals[4]—currently the fourth-highest emitting industrial sector—are *likely* to show the highest rate of emission growth of any major industrial sector through the end of the century, driven by demand for plastics and industrial chemicals. The use of plastics has ballooned in recent decades, and without a step change in plastic waste management or cost-effective decarbonization options, plastics production and emissions will continue to rise as economies grow.

FIGURE 21
Emissions by industrial sub-sector
Million metric tons of CO_2e, *likely* range (67% chance)



Source: Rhodium Climate Outlook

TACKLING EMISSIONS FROM CEMENT AND IRON & STEEL

Cement and iron & steel are today's second and third largest sources of industrial emissions, accounting for 34% of all industrial emissions. Going forward, both sectors see emissions fall through 2050 in our *likely* range. This is despite 13% demand growth relative to today (on average) as the emission intensity of production for both products falls (Figure 22).

We find that iron & steel experiences deeper emission cuts than cement, however, as it outpaces cement in per-ton emissions improvements. This is largely driven by a switch from a reliance on coal-based blast furnaces to already established and lower-carbon technologies. Most notable is the rise in recycled scrap use, which grows to meet 38% of steel demand in our mean projection by 2050, up from 24% today. Already dominant in many markets including the US, steel scrap processed in an electric arc furnace avoids the energy-intensive step of reducing virgin iron ore. Where steel is still made from ore, we see a shift towards natural gas direct reduced iron (DRI) plants, a more efficient and less emissions-intensive pathway than coal-based blast furnaces. Novel technologies, including retrofitting blast furnaces and traditional DRI plants with carbon capture (CCS)

[4] This excludes industrial hydrogen production for fertilizer and other chemicals, which is included in a separate H2 production subsector.

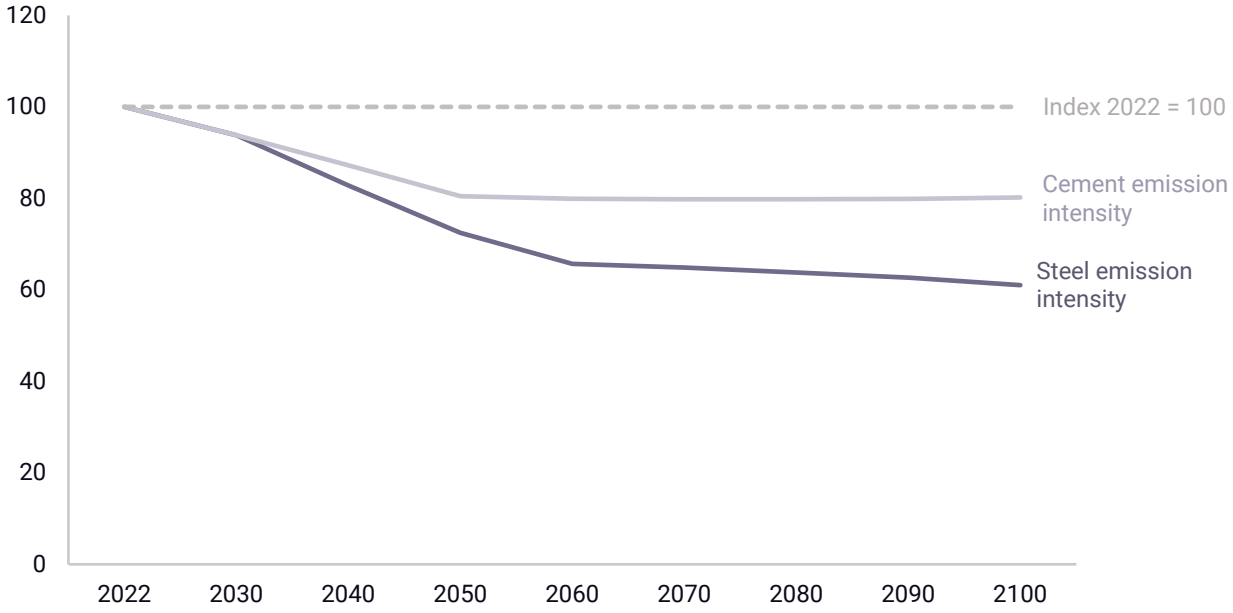
and DRI fueled with clean hydrogen also make gains, meeting 16% of production by 2050 on average.

It is important to note that we model deployment of both mature and emerging technologies for iron & steel decarbonization that are either widely used today (e.g., electric arc furnaces with scrap, natural gas and biomass in cement kilns), widely used in other applications, but not yet common (e.g., CCS), or which are built on existing processes (e.g., direct iron reduction with hydrogen, hydrogen in cement kilns). More nascent technologies or those that would require larger process or knowledge adaptation—like direct electrification for steel or electrochemical cement—could well deploy more in the future, but there is significant uncertainty in their potential cost trajectories.

FIGURE 22

Emissions fall for steel and cement despite growing demand

Mean projections, index 2022=100



Source: Rhodium Climate Outlook

Unlike iron and steel, few mature technologies exist today for reducing emissions from cement. In the absence of additional policy and innovation, cement decarbonization largely occurs from decreasing the amount of clinker—the emission-intensive backbone of cement—in every ton of product. Widely available materials like calcined clay, fly ash, and natural pozzolans are already part of cement formulation and can be substituted for up to 30-40% of clinker without compromising structural integrity, typically for lower cost. We project the global average clinker ratio to fall from 0.71 today to 0.64 by 2050 as the use of these compounds grows (Figure 24). Carbon capture in the production of clinker, along with many emerging technologies currently under development, could further reduce cement emissions. However, without greater policy support and investment, only a modest amount of carbon capture deploys in our RCO Baseline.

In both steel and cement production, the more mature pathways that contribute most to emissions reductions through 2050 have their limits. Recycled scrap can't meet 100% of rising global demand, and steel made from iron ore will need to fill the gap. While new

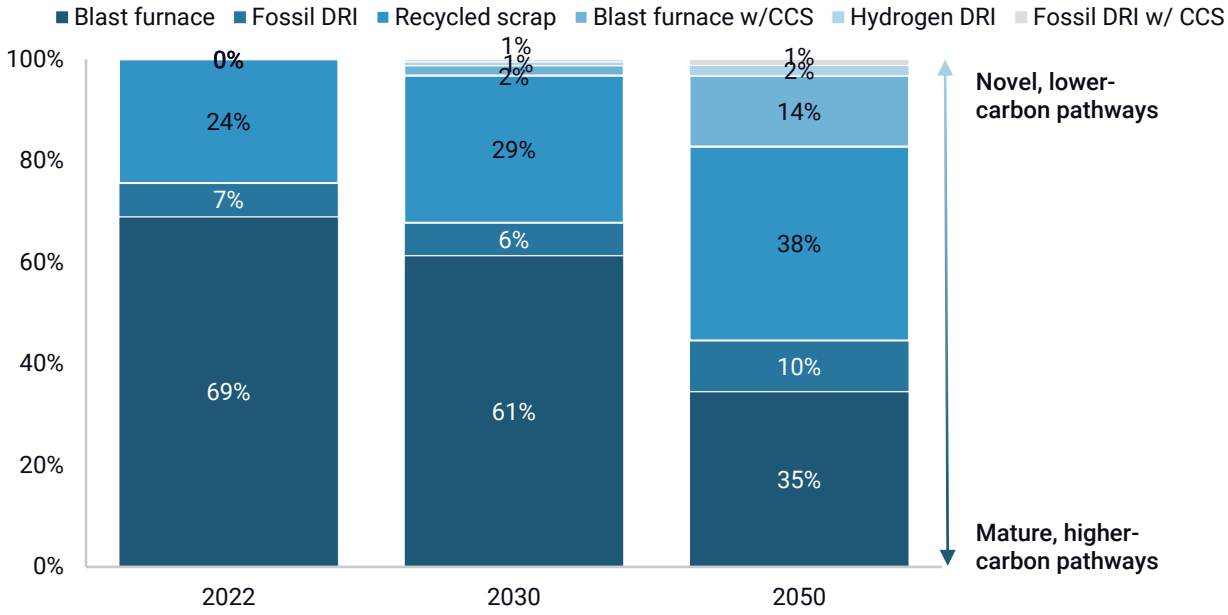
cement formulations under development can push the boundaries, the clinker ratio can only go so low while maintaining structural integrity. In the absence of additional innovation in nascent technologies, emissions in both industries have a 50% chance of leveling off or rising after 2050 as demand growth outpaces emission intensity improvements. To truly decarbonize, iron and steel and cement will need broad scale-up of clean technologies beyond those available today.

However, while the vast majority of novel clean technologies deploy in OECD countries and China—regions that see falling steel and cement production—the bulk of demand growth comes from the rest of the world. Countries outside of China and the OECD will produce one-third of global steel by 2050 in our mean projection—up from a fifth today—but only 2% of clean steel, including H2 DRI and CCS (Figure 25). The disparity is even more stark for cement, where 100% of cement with carbon capture deploys in OECD countries and China across all likely futures.

FIGURE 23

Inputs to steel production

Share of steel production by technology under RCO Baseline mean

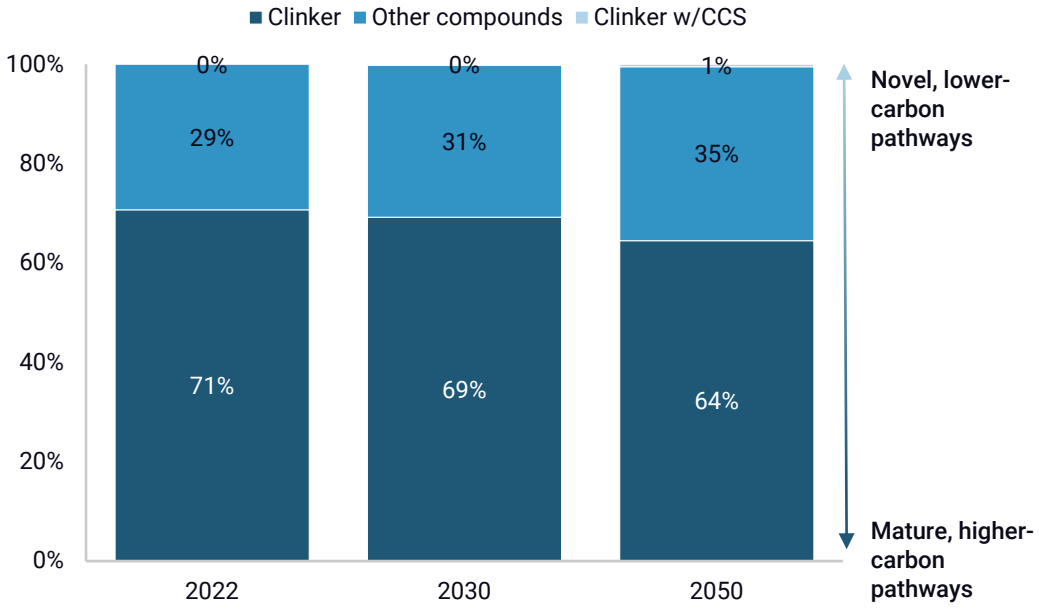


Source: Rhodium Climate Outlook

FIGURE 24

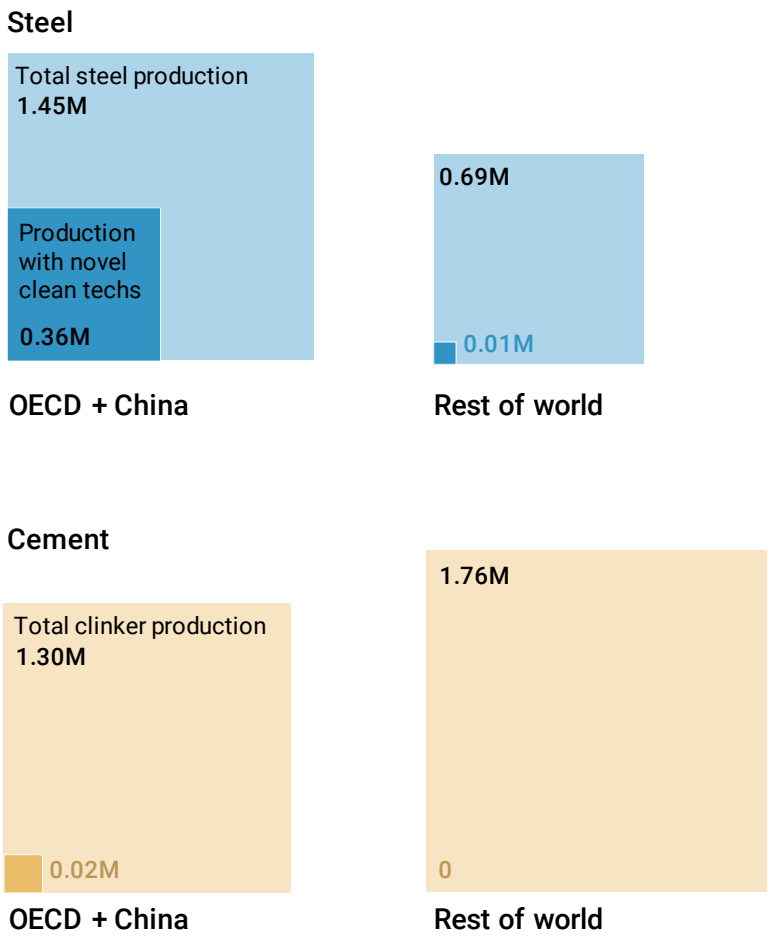
Inputs to cement production

Share of cement production by technology in RCO Baseline mean projection



Source: Rhodium Climate Outlook

FIGURE 25
Production of steel and cement in 2050
Mean projections, thousand metric tons

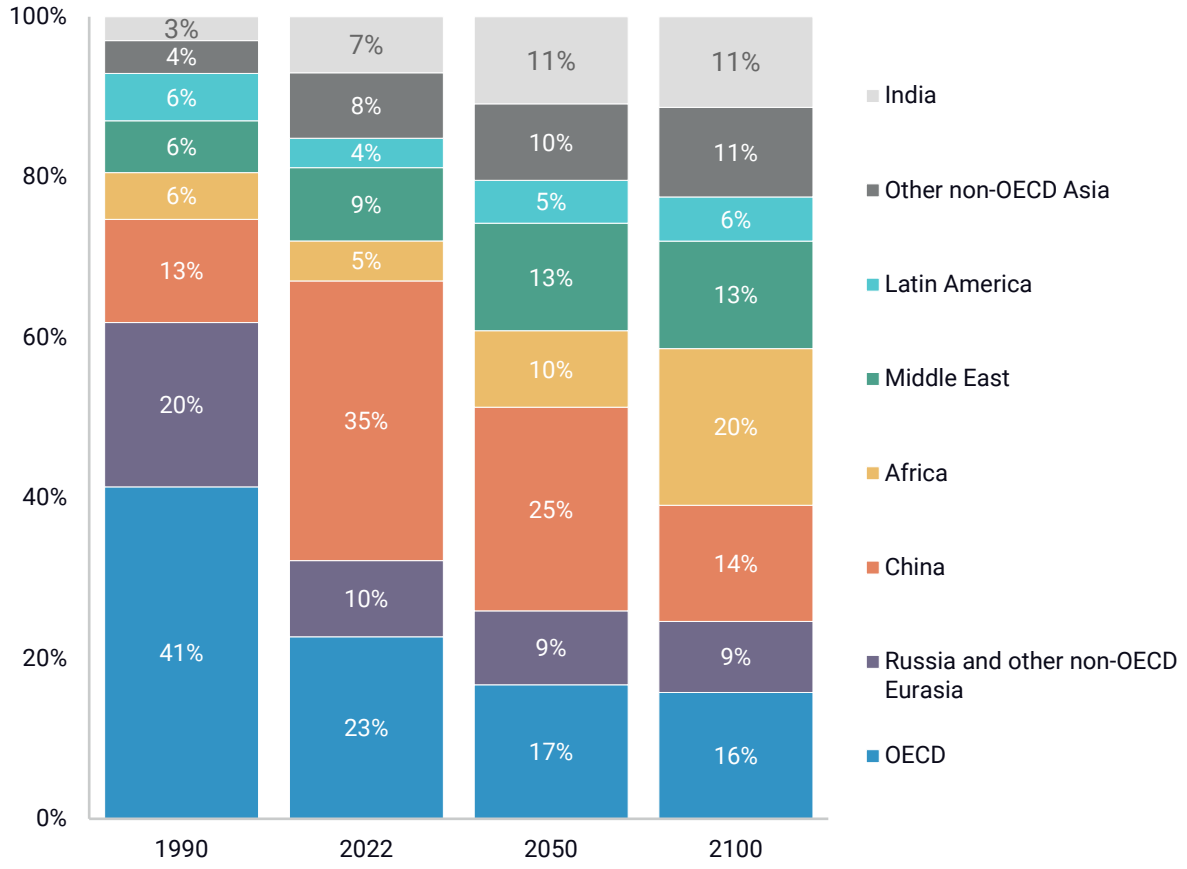


Source: Rhodium Climate Outlook

REGIONAL DYNAMICS IN THE INDUSTRIAL SECTOR

The demographic shift we observe in steel and cement production is mirrored in industrial trends as a whole. Today, China accounts for more than a third of the world's industrial emissions. By 2050, this share falls to a quarter on average due to overall structural decline, slowing urbanization, and a shrinking population (Figure 26). OECD countries' share also meaningfully shrinks while fast-growing regions fill in the gap. India's share of global industrial emissions grows substantially, driven by robust economic and population growth, as do contributions from other fast-growing regions, including Africa, the Middle East, and other non-OECD countries. As industrial emissions are increasingly spread across a broader set of actors, decarbonizing the sector will require making low-carbon technologies widely affordable and available outside of today's largest emitters.

FIGURE 26
Regional share of industrial emissions
Percent, projection mean



Source: Rhodium Climate Outlook

Agriculture and waste

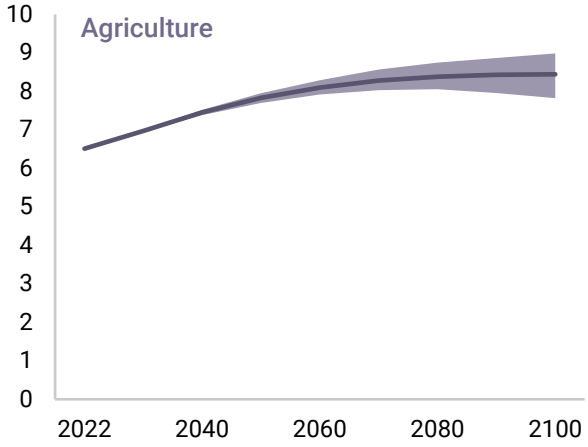
Today, emissions from agriculture and waste total 8.6 gigatons of CO_2e, contributing 17% of global GHG emissions. The vast majority of emissions from these sectors comes from methane (60% of agriculture and 90% of waste emissions). Over time, emissions from both sectors *likely* rise, driven by population and economic growth and the slow evolution of climate policy in these sectors worldwide. Unlike all other sectors of the economy, we do not model an evolution in policy in these sectors, due to a lack of sufficient historical experience of mitigation policy measures across a sufficient cross-section of countries. As a result, the RCO Baseline illustrates the *likely* emission trajectory for agriculture and waste emissions absent additional policy to drive deployment of cost-effective solutions for agriculture and waste.

Agricultural emissions—which include emissions from livestock, crops, and fuel consumption[5]—*likely* rise 18-22% through mid-century, with the bulk of emissions growth driven by emerging economies that expect to see significant population growth, including Africa, India, Brazil, and other non-OECD countries in Asia (Figure 27). The momentum in emissions from agriculture *likely* slows over time, and we see at least a 17% probability that emissions start to decline after 2080.

We find a similar trend in emissions from waste—including from landfills, wastewater treatment, and composting—with emissions *likely* rising 5-6% by mid-century and 10-21% by century's end (Figure 28).

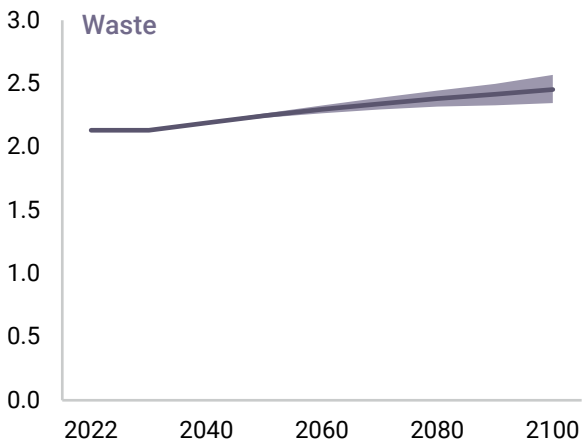
Without additional policy and innovation to help scale affordable mitigation solutions for agriculture and waste, especially in regions that expect to see significant population growth, emissions from agriculture and waste become a growing share of global emissions. In our projection mean, emissions from agriculture and waste grow from 17% of the global total today to 23% in 2050.

FIGURE 27
Agriculture emissions
Billion metric tons of CO_2e, *likely* range



Source: Rhodium Climate Outlook

FIGURE 28
Waste emissions
Billion metric tons of CO_2e, *likely* range



Source: Rhodium Climate Outlook

In the following chapter, we take a deeper look at the emissions outlook for the world's largest economies (the Group of 20) through 2035, the period in which the next round of NDCs will be set, in order to chart a path to future emission reductions consistent with meeting global net-zero goals.

[5] Emissions from agriculture exclude emissions from land use change. We include projected emissions and removals from forestry and other land use (FOLU) in our global, regional and national emissions totals, but we do not model the full potential range of possible FOLU outcomes. See the Technical Appendix for more details on how we treat FOLU.

CHAPTER 4

Setting the Stage for Ambitious 2035 NDCs

Given what we know about the likely outlook for global emissions absent an acceleration of climate and clean energy policy and innovation, it will be important for the world's major economies to chart a different path for the coming decade. A cornerstone of the 2015 Paris Agreement was the establishment of a process for UNFCCC Party countries to set national commitments for reducing emissions. These nationally determined contributions (NDCs) are submitted on a five-year cycle and are informed by the Global Stocktake, an assessment of global progress toward meeting the Paris Agreement goals of limiting warming to well below 2°C.

The Global Stocktake outcome, adopted last year at COP28 in Dubai, encouraged Parties to "come forward in their next nationally determined contributions with ambitious, economy-wide emission reduction targets, covering all greenhouse gases, sectors and categories and aligned with limiting global warming to 1.5 °C and to "align their next nationally determined contributions with long-term low greenhouse gas emission development strategies."

By early 2025, countries are expected to unveil new NDCs for the year 2035. This marks a critical juncture for the Paris Agreement and the NDC process. The 2035 NDCs will set the expected level of global ambition for the next decade and will be an important stepping stone on the path to net-zero emissions around mid-century. Since the last round of NDCs were submitted in 2020, the majority of countries, representing 88% of global emissions, have committed to reaching net-zero GHG emissions or carbon neutrality by mid-century.

As Parties prepare to announce their 2035 NDCs in a few months, it will be important to consider what each country is currently on track for (e.g. its baseline emissions pathways under current policy and energy market conditions) as a starting point for assessing what additional ambitious action can be taken. Currently, there is a lack of methodologically consistent, economy-wide emissions baselines for key economies against which to assess the level of ambition of proposed NDCs. In the last round of NDCs, the ambition of proposed 2030 NDCs was difficult to assess due to a lack of transparent information about the assumptions underlying the business-as-usual emissions projections used to set NDCs and measure progress. Countries' own projections, when made available, often excluded information about the expected pace of economic growth—a highly uncertain variable and a key driver of GHG emissions projections—among other assumptions critical to understanding a country's likely emissions trajectory.

To fill this gap, the RCO provides methodologically consistent economy-wide emissions projections for all G20 economies. By assessing country-level emissions under a range of potential economic and energy market futures, the RCO provides a comparable and consistent measure of what the world's major economies are likely on track for, including a full probability distribution of outcomes against which to assess not only the most likely outcome, but the full range of potential outcomes.

It is particularly important to stress the impact of the uncertainty in future economic growth on economies' baseline emissions pathways. One important innovation the RCO

provides is integration of probabilistic GDP futures in our GHG emissions projections. The pace of economic growth is the single most important determinant of future GHG emissions and can be highly uncertain. Nearly all other current sources of emissions projections rely on a single deterministic pathway for GDP (often relying on the same single source).

The RCO's approach to the uncertainty in GDP projections provides deeper insights into the upside and downside risk of slower or faster economic growth than the default central estimates others have used to date. For economies with business-as-usual or CO_2-intensity NDC targets for 2030 (including China, India, Indonesia, Mexico, Saudi Arabia and Turkey), the uncertainty around actual GDP levels means there is no single NDC emissions level to aim for. If actual economic growth is slower or faster than expected back in 2020 when NDCs were set, the emissions impact of achieving NDC targets will also differ significantly.

As today's top emitter, there's no country where the economic outlook matters more for global emissions than in China. There is a growing consensus, including among Rhodium Group's China markets experts, that China's growth will likely decelerate in the coming decades as a result of slowing productivity growth and a shrinking population. In our RCO mean projection, China's economy grows at an annual average rate of 3.2% over the coming decade. This meaningfully diverges from other available emissions projections, which often rely on Beijing's target of around 5% annual growth. Critically, our outlook also considers uncertainty in the pace of growth—with a likely range of average annual growth from 2.8-4.7% and very likely range of 1.2-6.4%—which has important implications for China's baseline and 2030 NDC emissions.

As a starting point for setting expectations for 2035 NDCs, we take a deeper look at G20 economies' 2030 NDCs and assess the probability that they are on track to meet those targets in the section below.[6] In the following section we assess the outlook for G20 economies' emissions in 2035 and compare that to a straight-line trajectory from their 2030 NDC to their nationally-determined mid-century net-zero commitments.

G20 progress toward 2030 NDCs

Among the G20 economies, there are three primary types of NDCs for the period ending in 2030:

- **Absolute, economy-wide GHG emission reduction targets**: Argentina, Australia, Brazil, Canada, EU, Japan, South Korea, Russia, South Africa, UK, US
- **Reductions from a business-as-usual (BAU) scenario**: Indonesia, Mexico, Saudi Arabia, Turkey
- **Emission intensity (CO_2 per GDP) and share of energy from non-fossil sources**: China, India

For this analysis, we model the emissions implications of meeting G20 economies' current 2030 NDCs based on available information submitted by Parties with their NDCs. We

[6] We assess all G20 nations except for EU member states, which are included as part of the EU-27.

assess only unconditional NDCs and exclude those that are predicated on receiving international financial support or other conditions.

We find that for six countries (Australia, China, Indonesia, Japan, and Russia), 2030 NDC emission levels align with their projected baseline emissions, signaling that those countries are on track today to meet their NDCs. Brazil's 2030 NDC falls at the very far edge of the RCO Baseline *likely* range, which means there is a small probability (less than 17%) that Brazil's current trajectory meets its 2030 NDC. The outlook for China, in particular, has changed considerably since its 2030 NDC was set five years ago. Despite the absence of an absolute emission reduction target, we find that China's emissions are *likely* on track to decline 11-19% below 2022 peak levels by 2030, keeping them in line to meet the 60-65% reduction in carbon intensity and 25% non-fossil energy consumption targets under their 2030 NDC.

We project that three countries (India, Mexico, and Turkey) are very likely to over-deliver on their 2030 NDCs given their current trajectories. For Mexico and Turkey, this is due in large part to the fact that these countries adopted BAU targets that overestimated the potential for emissions growth at the time of NDC submission in 2020 and locked in 2030 targets that exceeded their actual emissions path.

For India, its 2030 NDC is a bit of a moving target as the primary binding constraint on emissions is the commitment to reduce the emissions intensity of its economy 45% below 2005 levels. The emissions impact of an intensity target like India's depends highly on the anticipated pace of economic growth through 2030. Between 2005 and today, India's GHG emissions have doubled, but its GDP increased by nearly four-fold, putting India on track to reduce its emissions intensity by about half (achieving their 45% target). We don't yet know how much India's economy will grow between now and 2030. The wide range of emissions outcomes associated with meeting India's NDC in 2030 in our modeling represents the wide range of potential economic futures in which India continues to meet its 45% emission intensity goal (along with its non-fossil and land sink components of its NDC). In our RCO Baseline for India, we find that India has a more than 90% chance of outperforming its 2030 NDC.

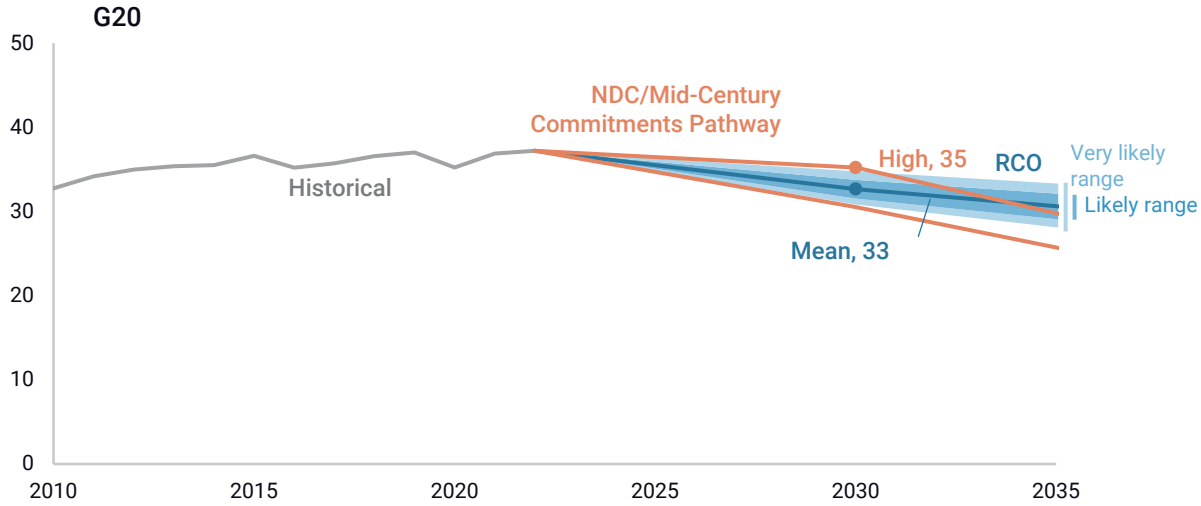
Finally, we find that the following seven countries are currently off track to meet their 2030 NDCs: Argentina, Canada, the EU-27, South Korea, South Africa, the UK, and the US. For most of these economies, their RCO Baseline emissions are directionally on the right track, trending down through 2030, but just not fast enough to meet their NDCs. For two countries—Argentina and South Africa—we find that emissions are trending in the wrong direction, likely rising from today's levels.

We don't include Saudi Arabia in any of the categories above because of a lack of clarity about its NDC. The updated NDC specifies a target of reducing emissions 278 million metric tons of CO_2e below two potential dynamic BAU scenarios, about which they provide no information. For the purposes of this analysis, we assume Saudi Arabia's emissions follow the RCO Baseline range through 2030.

On the whole, most G20 economies are on track or are within striking distance of meeting their 2030 NDCs (Figure 29). As a group, G20 economies are *likely* on track to decrease their GHG emissions 9-15% below 2019 levels by 2030, absent a significant acceleration of climate and clean energy policy. If all G20 economies met their current 2030 NDC

commitments (and none overachieved them), the G20 as a whole would decrease emissions by only 7-14% below 2019 levels by 2030. That's less than they are *likely* on track for today.

FIGURE 29
G20 aggregate GHG emissions under RCO Baseline and straight-line path from current NDC and mid-century commitments
Net emissions (million metric tons of CO2e), likely and very likely range, mean



Source: Rhodium Climate Outlook

G20 outlook for 2035

As part of the Paris Agreement, countries also agreed to establish "long-term low greenhouse gas emission development strategies" (commonly referred to as net-zero targets). To date, countries representing 88% of global emissions have established net-zero or carbon neutrality targets in law or other policy documents or announced by the head of state. All but one G20 country (Mexico) has adopted or announced a net-zero emissions target in the 2050-2070 timeframe. Of the remaining G20 economies, all but China and Saudi Arabia have specified that their mid-century targets include all greenhouse gases, not just carbon dioxide.

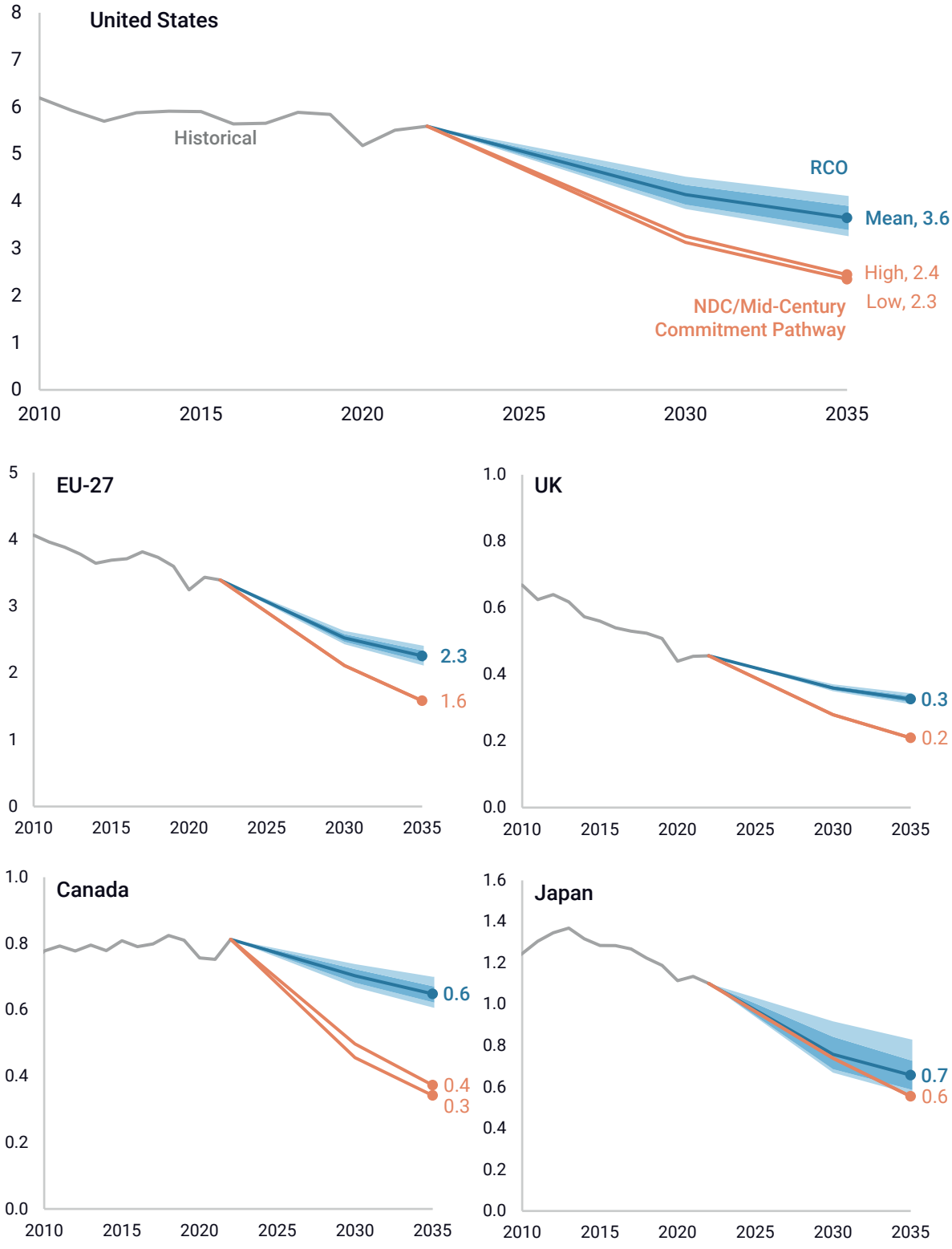
To provide a useful starting point for setting expectations for 2035, we assess G20 economies' projected emissions in 2035 under our RCO Baseline and compare it to where emissions would be in 2035 if each economy followed a straight-line path from their 2030 NDC to their mid-century targets (e.g., their **Current Mid-Century Commitment** scenarios) (Figure 30).[7] For countries that currently only have carbon neutrality targets for mid-century (i.e., China and Saudi Arabia), we also include a look at an alternative straight-line path from 2030 NDCs to net-zero GHGs in their mid-century target year of 2060. We report all projected emissions levels in 2035 under our RCO Baseline's *very likely* range (90% probability of occurring) and under a pathway to mid-century commitments, as well as the change from 2019 levels in Table 1 at the end of this chapter (data is also available in the ClimateDeck).

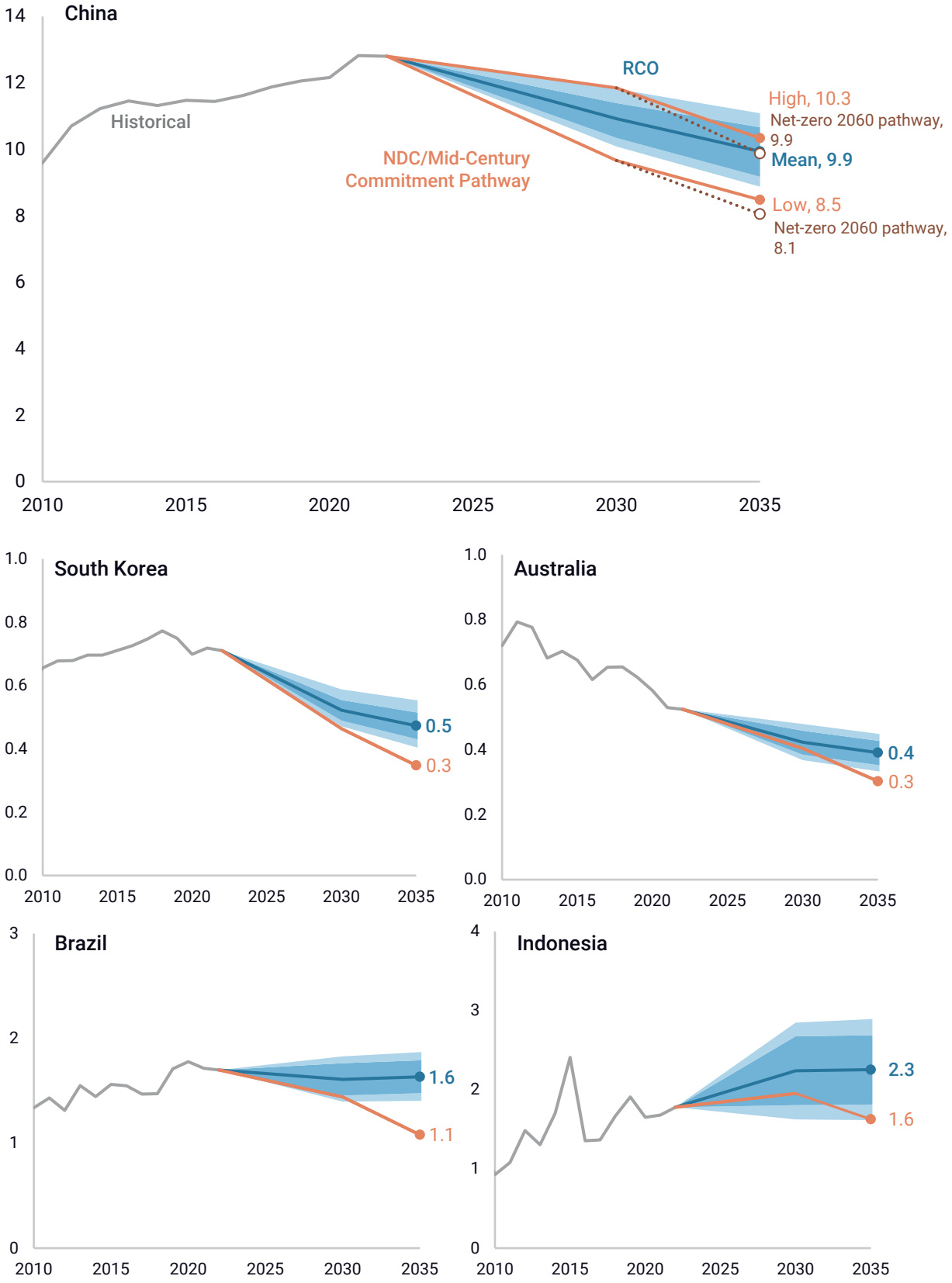
[7] In the absence of an announced mid-century target by Mexico, we charted an illustrative path from Mexico's 2030 NDC to net-zero by 2060.

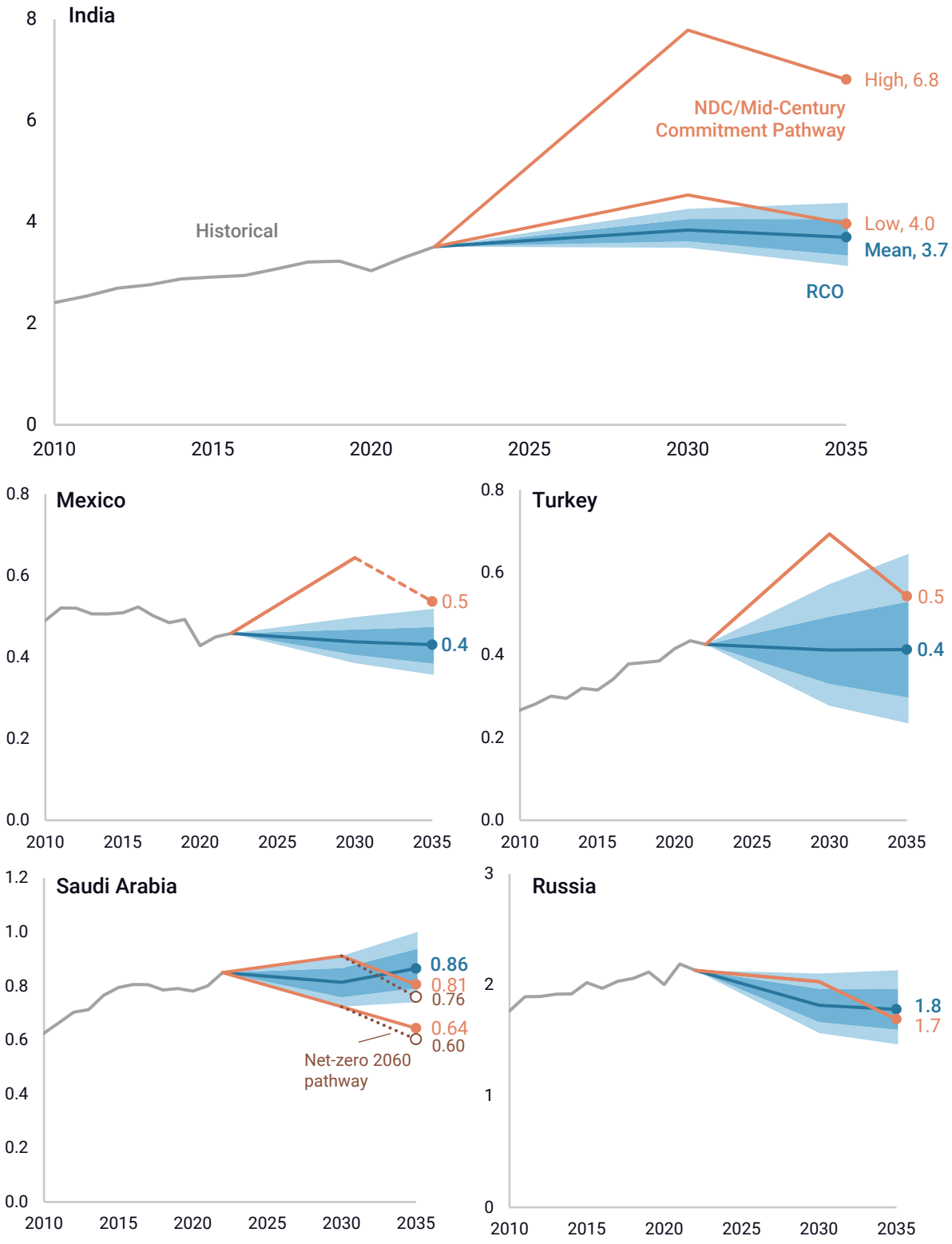
FIGURE 30

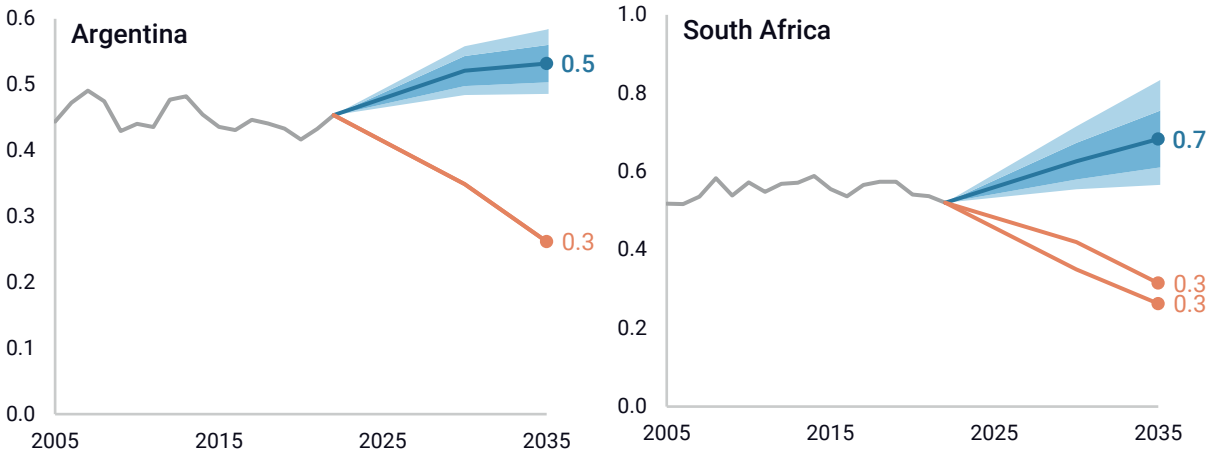
G20 GHG emissions under RCO Baseline and straight-line path to current NDC and mid-century commitments

Net emissions (billion metric tons of CO_2e)




China
Historical
RCO
NDC/Mid-Century Commitment Pathway
High, 10.3
Net-zero 2060 pathway, 9.9
Mean, 9.9
Low, 8.5
Net-zero 2060 pathway, 8.1
South Korea
0.5
0.3
Australia
0.4
0.3
Brazil
1.6
1.1
Indonesia
2.3
1.6


India
High, 6.8
NDC/Mid-Century
Commitment Pathway
Historical
Low, 4.0
Mean, 3.7
RCO
Mexico
0.5
0.4
Turkey
0.5
0.4
Saudi Arabia
0.86
0.81
0.76
0.64
0.60
Net-zero 2060
pathway
Russia
1.8
1.7



Source: Rhodium Climate Outlook. Dashed lines represent potential expanded mid-century targets, not those already committed to date.

If all G20 economies set 2035 NDCs that follow a straight-line path from their 2030 NDCs to their existing mid-century net-zero commitments (and if Mexico were to adopt a 2060 net-zero target), the G20 as a whole would be on track to reduce emissions 21-28% below 2019 levels by 2035.

Aligning 2035 NDCs with countries' existing net-zero goals would not significantly alter the rankings of the world's highest-emitting G20 economies. Figure 31 shows how the rank order of top emitters today (2022) would change if G20 economies set 2035 targets in line with their existing mid-century targets (projection mean). China would retain its place as the world's largest emitter by far. India would surpass the US as the second largest emitter, dropping the US down to third, with Indonesia rising to claim the title as fourth largest emitter. The EU-27 would drop from third to sixth as Russia would maintain its spot in fifth.

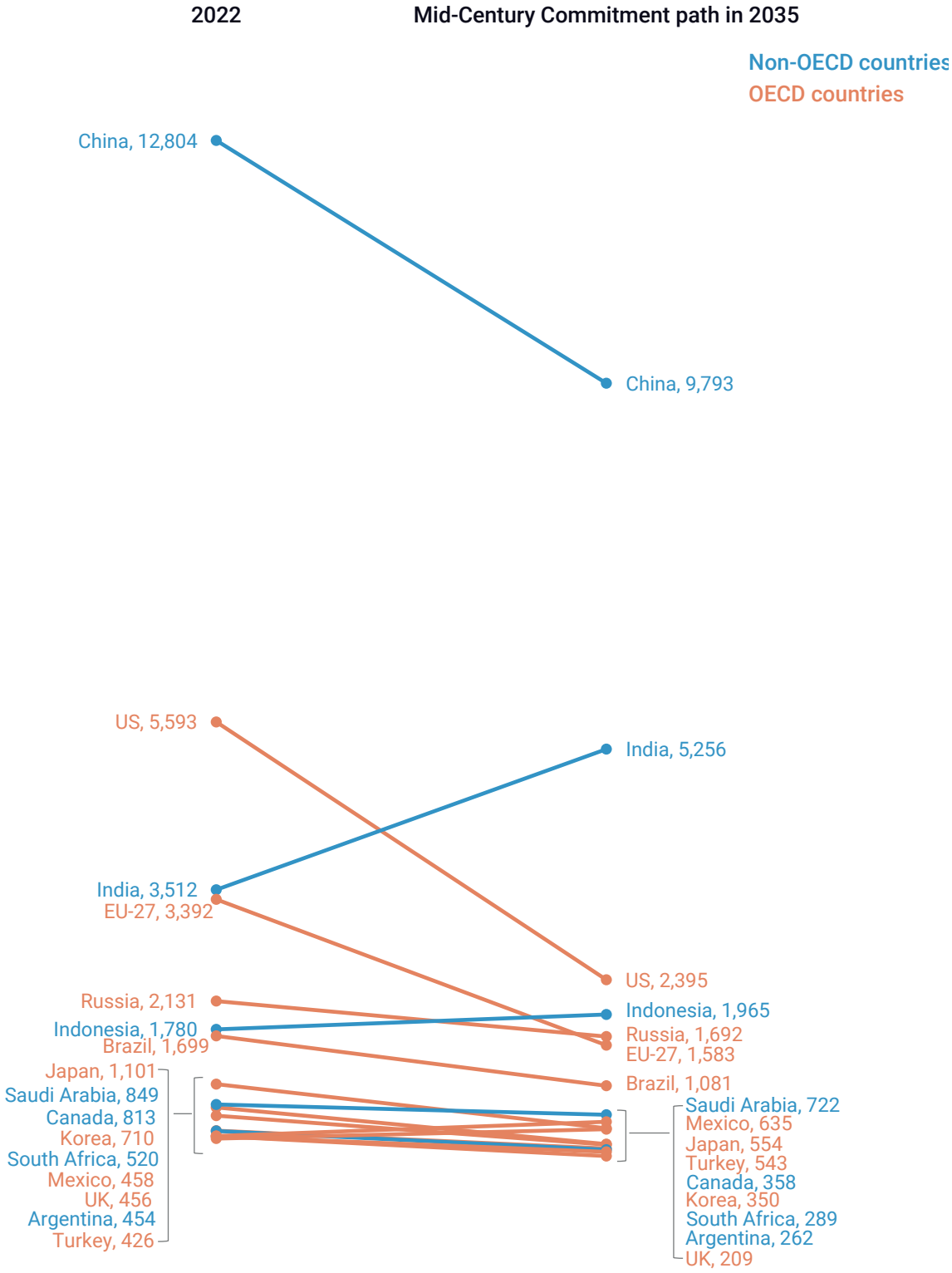
Perhaps more interestingly, the per capita emissions of G20 economies would display a more dramatic shift (Figure 32). Nearly all G20 economies would experience a significant decline in per capita emissions, with the exception of India, Mexico, and Turkey. Australia, Canada, the EU-27, South Korea, the US, and the UK would see per capita emissions drop by half or more in just over a decade. The average per capita emissions of all OECD economies would also drop by nearly half from 9.8 tons per capita to 5.0 by 2035, converging with the average level with non-OECD economies which would rise from 5.5 tons per capita today.

If G20 economies adopted 2035 NDCs that align with a straight-line to their net zero targets, there would be a convergence of per capita emissions for most economies in the 3-7 tons per capita range. China, Indonesia, South Korea, and the US would all converge at around 6.5-7 tons per capita, while Brazil, Japan, Mexico, and South Africa converge at 4.3-4.8 tons. Per capita emissions in the EU and UK drop from around 6 tons per capita to around 3, converging with India, which rises from 2.5 tons per capita today.

FIGURE 31

Net GHG emissions of G20 economies

Historical and projected mean under the **Current Mid-Century Commitment** scenario (million metric tons of CO_2e)

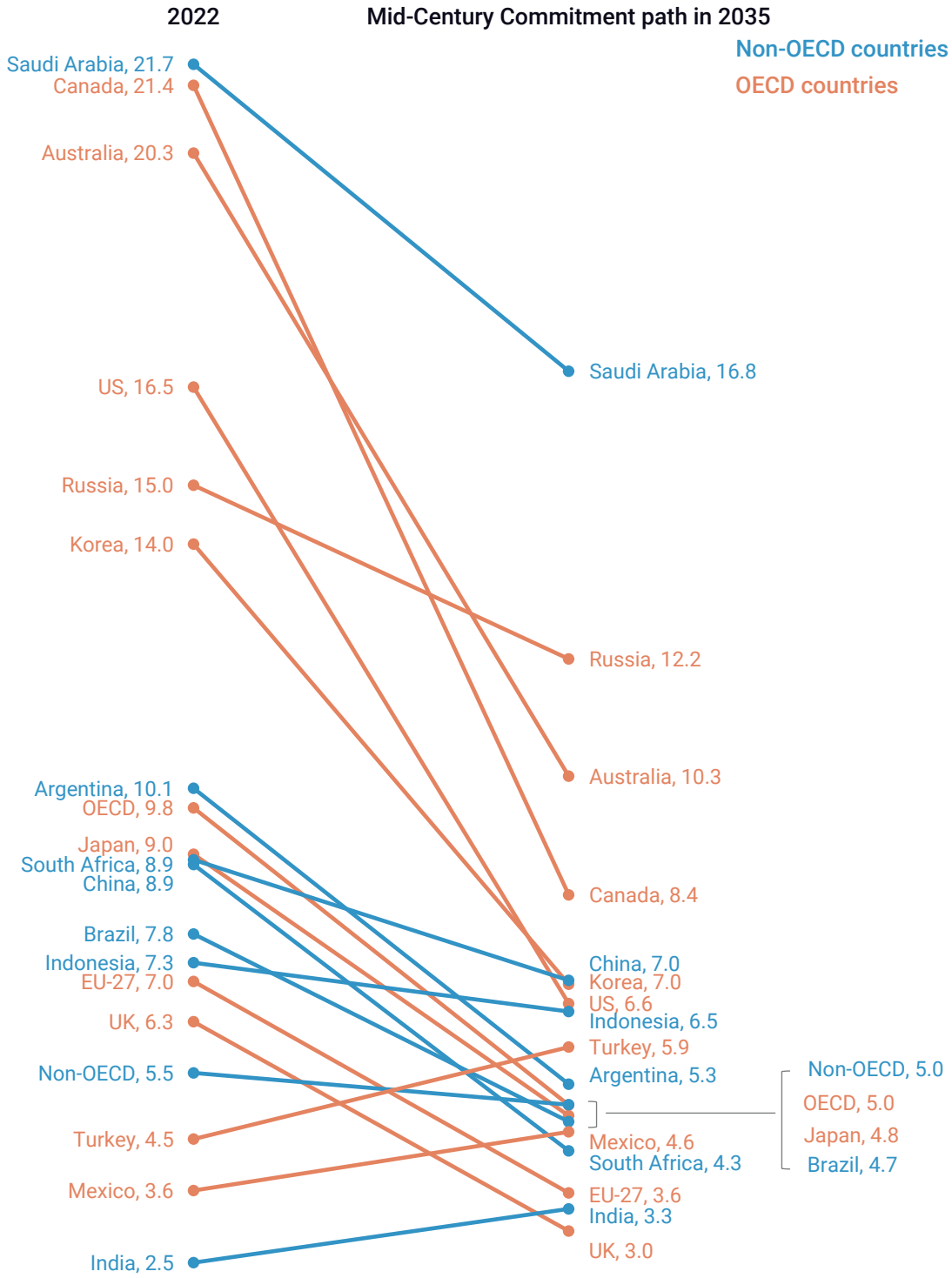


Source: Rhodium Climate Outlook

FIGURE 32

Per capita GHG emissions of G20 economies

Historical and projected mean under the Current Mid-Century Commitments scenario (metric tons of CO_2e per person)



Source: Rhodium Climate Outlook

TABLE 1
G20 GHG Emissions

	RCO Baseline (very *likely* range)		Mid-Century Commitments Pathway	
	2035 Emissions Million metric tons of CO_2e	**% Change from 2019**	**2035 Emissions** Million metric tons of CO_2e	**% Change from 2019**
Argentina	503 to 560	+16% to +29%	262	-40%
Australia	353 to 427	-31% to -43%	303	-51%
Brazil	1,478 to 1,791	-14% to +5%	1,081	-37%
Canada	623 to 672	-17% to -23%	342 to 373	-54% to -58%
China	9,174 to 10,668	-12% to -24%	9,178 to 10,327	-14% to -30%
China Net-Zero 2060			*8,053 to 9,875*	*-18% to -33%*
EU-27	2,171 to 2,338	-35% to -40%	1,583	-56%
India	3,341 to 4,057	+4% to +26%	4,418 to 6,053	+37% to +88%
Indonesia	1,814 to 2,689	-5% to +41%	1,910 to 2,020	+0% to +6%
Japan	588 to 730	-39% to -51%	554	-53%
Korea	431 to 515	-31% to -42%	349 to 352	-54%
Mexico*	384 to 474	-4% to -22%	597 to 671	+21% to +36%
Russia	1,598 to 1,961	-7% to -24%	1,692	-20%
Saudi Arabia	791 to 937	0% to +18%	674 to 767	-3% to -15%
Saudi Arabia Net-Zero 2060			*602 to 759*	*-4% to -24%*
South Africa	610 to 754	+6% to +31%	263 to 315	-45% to -54%
Turkey	298 to 529	-23% to +37%	543	+41%
UK	316 to 335	-34% to -38%	209	-59%
USA	3,396 to 3,906	-33% to -42%	2346 to 2444	-58% to -60%

Source: Rhodium Climate Outlook. *Mexico has not announced a mid-century target. For illustrative purposes here we chart a course to net-zero by 2060.

CHAPTER 5

Conclusion

In this second edition of the Rhodium Climate Outlook, we hope to provide a bit more nuance to the question "what are we on track for?" in terms of global emissions and temperature rise. We focus particularly on the outlook for baseline emissions in the coming decade as a starting point to inform countries as they prepare to submit their nationally-determined contributions for 2035.

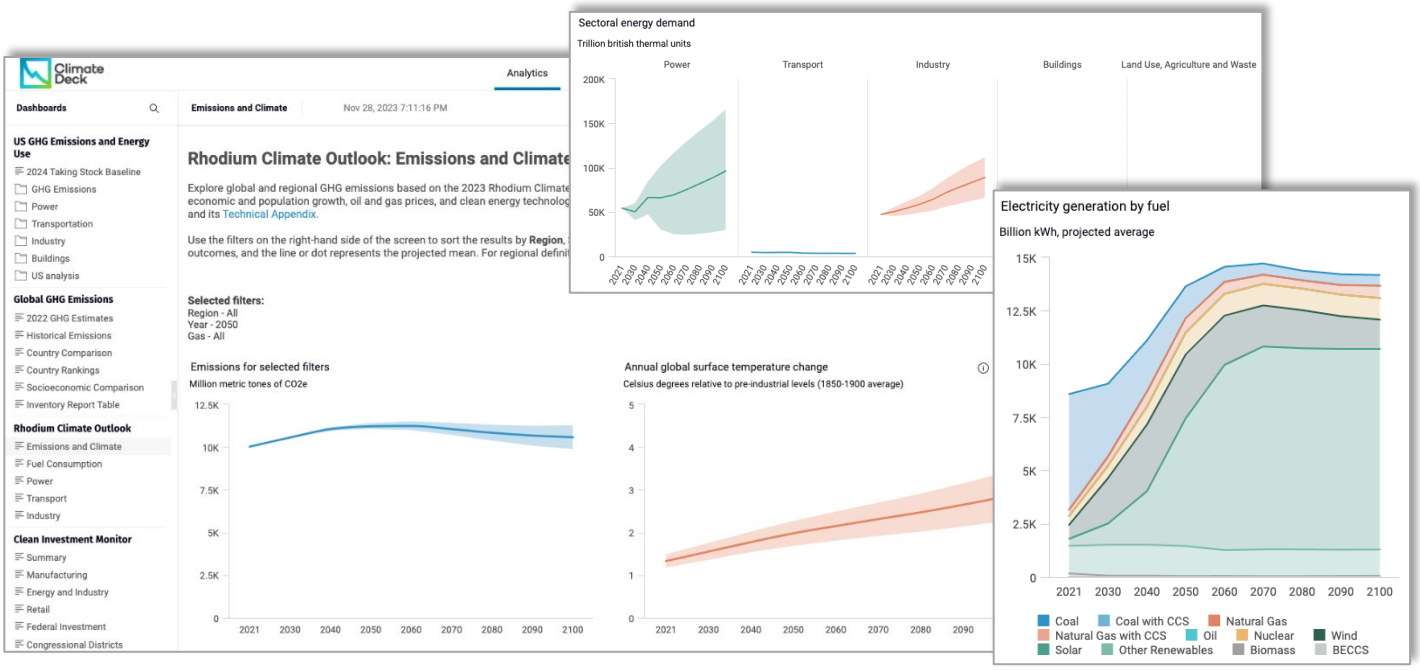
We find that while we have successfully avoided the most catastrophic temperature rise projected just a decade ago, we are *very unlikely* to be on track for keeping temperature rise below 2°C, absent accelerated policy and innovation. Despite significant progress in decarbonizing power and road transport, we see diminishing returns unless accelerated policy helps make mature technologies available to all regions of the world and additional innovation helps deliver solutions that can meet the growing demand that results from widespread economic growth. Addressing the rise of industrial emissions will also require significant additional policy and innovation to bring emerging clean technologies to market and bring their costs down sufficiently to be cost-competitive with their fossil counterparts in all regions of the world.

The good news is that if countries chart a path to meeting their own nationally-determined mid-century net-zero or carbon neutrality targets, the likelihood of keeping global mean temperature rise below 2°C rises from less than 7% to as much as 68%. If remaining countries adopt net-zero by 2070 targets and countries update their existing carbon-neutrality targets to include all GHGs, that likelihood rises to an astonishing 96% and puts 1.5°C within reach (67% chance) by century's end. That's a far cry from what the world was on track for only nine years ago when the Paris Agreement was adopted. If countries adopt 2035 NDCs that set them on a course for net-zero GHGs by mid-century and implement those pledges, the world has a solid chance of avoiding the very worst impacts of climate change.

Each year, the Rhodium Climate Outlook will provide an updated look at what the world is on track for given a wide range of developments with impacts on our key variables. As we narrow down uncertainty, add emerging technologies that have reached sufficient maturity, and incorporate new policies as they become adopted, we hope to see the outlook for global emissions and temperature rise align more closely with a path to global decarbonization around mid-century and global mean temperature rise well below 2°C. In the years ahead, the RCO will be an important barometer to assess what really matters, where the world must focus, and how our efforts are paying off.

For more information about accessing all the rich, underlying data from the RCO, see the next section on our free ClimateDeck data visualization platform.

ClimateDeck | Rhodium Group & Breakthrough Energy



The ClimateDeck—a partnership of Rhodium Group and Breakthrough Energy—is an interactive data platform that enables you to explore global and US 50-state greenhouse gas (GHG) emissions data and projections and energy market outlooks.

Unlock insights with Rhodium Climate Outlook data

Dive into the Rhodium Climate Outlook dashboards to answer your global and regional climate-related questions. Whether you are analyzing emissions trends, forecasting energy market shifts, or assessing the potential for emerging climate technologies, the ClimateDeck offers the tools to customize your analysis. The ClimateDeck equips users with comprehensive datasets, unique and responsive insights, and a robust set of tools. Users are empowered to track pathways to climate targets and understand the implications of major developments at the international, national, and state levels.

Explore, customize, and share

All of the underlying data from the Rhodium Climate Outlook is available to explore and download from the ClimateDeck. Use its intuitive interface to tailor data visualizations by adjusting inputs such as timeframe, geography, sector, gas and uncertainty ranges. The adjustable datasets can be exported as production-ready visualizations and CSV files to seamlessly integrate into your work. Incorporate ClimateDeck data in your own analysis and external publications, with attribution to Rhodium Group. Access the full suite of Rhodium Climate Outlook data for free. For access and more information, please email climatedeck@rhg.com.

About Rhodium Group

Rhodium Group is an independent research provider combining economic data and policy insight to analyze global trends. Rhodium's Energy & Climate team analyzes the market impact of energy and climate policy and the economic risks of global climate change. This interdisciplinary group of policy experts, economic analysts, energy modelers, data engineers, and climate scientists supports decision-makers in the public, financial services, corporate, philanthropic and nonprofit sectors. More information is available at www.rhg.com.

Acknowledgements

Funding for the Rhodium Climate Outlook is provided by Breakthrough Energy as part of their support for the ClimateDeck, a partnership of Rhodium Group and Breakthrough Energy.

The authors would like to acknowledge the contributions of Rhodium team members that supported this work, including Jaspreet Sohal, Maggie Young, Kelly McCusker and Trevor Houser.

Disclosures

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