PBL Netherlands Environmental Assessment Agency

# EMISSION PATHWAYS AND CLIMATE TARGETS

## Exploring the emission gap and financing needs in low- and middle-income countries

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## Colophon

**Emission pathways and climate targets. Exploring the emission gap and financing needs in low- and middle-income countries**


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# Summary


### *Introduction*

The Paris Agreement aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to keep warming below 1.5 degrees Celsius. Each signing country's commitment to the agreement is outlined through Nationally Determined Contributions (NDCs), with 195 countries submitting these in the first round. The historical contributions to climate change, along with its impacts and associated policies, are not equally distributed across countries, however. Historically, most of the high-income countries have been the primary contributors to increased greenhouse gas (GHG) emissions. Currently, low- and middle-income countries (LMICs) also contribute significantly to global emissions, though their per capita emissions remain comparatively low. LMICs are among those most impacted by climate change, already facing consequences such as droughts, floods, and extreme weather events. These countries are caught in a dilemma of balancing economic development with emissions reduction, as rapid industrialisation and reliance on fossil fuels for energy generation could further exacerbate emissions.

Scientific consensus indicates that the severity of climate change impacts intensifies as global mean temperatures rise further. If the global temperature increase could be limited to 1.5 degrees Celsius, the resulting climate impacts would be significantly less severe than those projected under the current policy scenario, which could lead to a warming of 2.5 to 3.5 degrees Celsius. For this, human-induced emissions must achieve climate neutrality by 2050 (IPCC 2018). Achieving global climate neutrality demands considerable investments in technology and infrastructure, which is a substantial challenge for LMICs due to a significant financing gap. Addressing this issue requires collaboration among governments, international bodies, the private sector, and civil society, focusing on fair emission reduction targets, an equitable resource distribution, and sustainable development strategies.

### *Methods and tools*

In response to a request from the Directorate-General for International Cooperation (DGIS) of the Netherlands to identify potential emission reduction sectors and associated costs, this study explores regional mitigation potentials and identifies the emission and financing gaps required to achieve agreed climate goals, with a particular emphasis on selected priority regions: Brazil, Indonesia, South Africa, and Western Africa (particularly Nigeria and Senegal). To meet this aim, we explore three sets of scenarios: regional climate policy scenarios, cost-effective mitigation scenarios, and effort-sharing scenarios. For further details on these, please refer to Chapter 2.

- The regional policy scenarios set covers the regional current policies, which explores the impact of policies already in place or accepted to legislators, and the NDCs scenario that explores the impact of submitted NDCs. In our calculations, we assume a continuation of similar efforts after 2030.
- The cost-effective scenarios explore pathways to achieve climate goals at the lowest possible cost at a global level. The assumption behind these scenarios is that high-income regions where mitigation costs can be high, will not only focus on their domestic reduction targets but also support emissions reductions in low-income regions.
- The fair-share scenarios assesses how emissions reductions can be distributed equitably across countries and regions, guided by fairness principles such as responsibility, capability,

and equality. The scenarios consider various factors including historical emissions, economic capabilities, and development needs but they do not consider cost effectiveness of emission reduction.

This study employs the IMAGE Integrated Assessment Model supported with a literature review to answer several research questions. These include the exploration of the emission gap in various climate change mitigation pathways, investigating the roles of key sectors in climate change mitigation, policy costs associated with these pathways, and the influence of socio-economic projections and varying cost of capital on the model outcomes. We identify gaps in the regional policy scenarios both in terms of regional emission reductions and associated policy costs when compared with the cost-effective pathways to meet climate targets. This provides critical policy insights that are essential for achieving climate mitigation targets. We also provide a brief overview of fair-share scenarios to highlight the need for international collaboration in technology transfer and financial support to achieve the climate targets collectively.

Our mitigation scenario outcomes are sensitive to factors like socio-economic developments and access to financial resources, i.e. the weighted average cost of capital (WACC). Socio-economic elements such as population growth, economic development, and technological progress influence mitigation actions and policy costs. While our primary analysis uses middle-of-the-road shared socio-economic projections (SSP2), we also compare scenarios using sustainable pathway projections (SSP1). Our cost-effective scenarios assume a uniform global WACC to enable affordable collective mitigation. However, WACC varies by risk-free rates, country premiums, and sector-specific rates, affecting clean energy investments across regions. Due to the urgency of climate action, we also explore scenarios with regional WACC variations: one with rapid convergence to OECD levels by 2050, and another with slower convergence, maintaining disparities until the end of the century.

### *There is a substantial gap between current policies and cost-effective pathways to meet the Paris goals*

As of January 2025, the remaining emission budgets to keep temperature below the Paris goals are 235 Gt $CO_2$ for 1.5 °C and 1110 Gt $CO_2$ for 2 °C (67% probability; as interpretation of well below 2 °C.) Under the Extended Current Policies scenario, global greenhouse gas (GHG) emissions are projected to stabilise around 50.5 Gt $CO_2$e by 2050, which is slightly lower than the median projected emission of 56 Gt $CO_2$e reported by United Nations Environment Programme (2024). This would result in cumulative $CO_2$ emissions of 1205 Gt $CO_2$ between 2020 and 2050 that, together with the emissions of other greenhouse gases, could lead to a 3 °C warming by 2100.

With the full implementation of the Nationally Determined Contributions (NDCs), GHG emissions are projected to slowly decline until 2030, achieving an average annual reduction of 0.6%. The continuation of this effort would result in emissions reaching 43 Gt $CO_2$e by 2050. The resulting cumulative $CO_2$ emissions of 1130 Gt $CO_2$ between 2020 and 2050 could lead to a 2.2 °C increase at the end of the century. Figure 1 shows the cumulative regional $CO_2$ emissions between 2020 and 2050 in the regional policy scenarios and the global cost-effective scenarios for the focus regions.

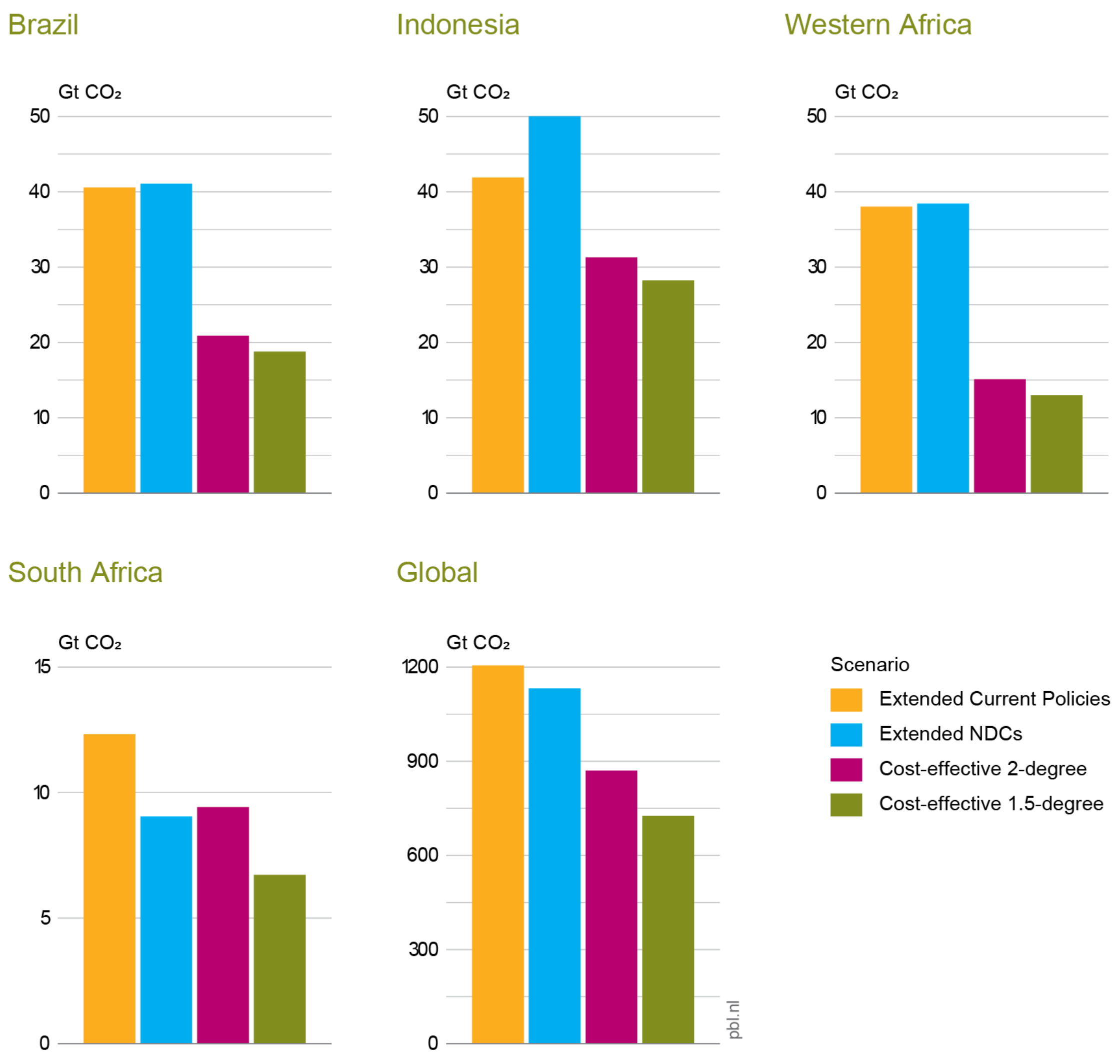



**Figure 1**
Cumulative net regional $CO_2$ emissions between 2020 and 2050 under various scenarios

*Note: See Figure 4 and Table 11 in Appendix 1 for regional grouping in IMAGE.*

In the regional policy scenarios, emission reductions vary significantly by region; wealthier regions show greater declines compared to low- and middle-income regions (LMICs) where emissions and energy demand continue to rise driven by growing population and economic development. For instance, emissions rise considerably in Sub-Saharan Africa, India, the Middle East and North Africa (MENA) under the Extended Current Policies scenario, while fossil fuels, especially coal, dominate the energy mix. Globally, renewables expand rapidly but require greater scale for substantial impact in emission reduction. The emission gap between the Extended Current Policies and Extended NDCs scenarios is 7 Gt $CO_2e$ by 2050, but both pathways are insufficient to meet the Paris Agreement goals.

In the well-below 2-degree scenario, global emissions are projected to reduce by 65% by 2050 relative to 2020, but fossil fuels continue to play a role in the energy system. The 1.5-degree scenario is projected to achieve an 80% emission reduction by 2050 relative to 2020, with substantial fossil fuel decline and a rapid increase in low-carbon energy sources. Our model projection of 19 Gt $CO_2e$ for well-below 2-degree and 10 Gt $CO_2e$ for 1.5-degree in 2050 is close to emission projections of 20 Gt $CO_2e$ and 8 Gt $CO_2e$ reported in United Nations Environment Programme (2024) for well-below 2-degree and 1.5-degree scenarios, respectively. Given 2030 is less than five years away, both cost-optimal mitigation pathways project a rapid decline in the decades after 2030 to compensate for delayed action. This results in lower emission gaps with current policies and NDCs until 2030. The projected emissions gap between the Extended Current Policies and the global cost-optimal pathway aimed at well below 2-degree and 1.5-degree in 2050 is 31 – 40 Gt $CO_2e$, lower than the median gap of 36 – 48 Gt $CO_2e$, but well within the range reported in United Nations Environment Programme (2024). The projected ambitions gap between Extended NDCs and cost-optimal pathways is 24 – 33 Gt $CO_2e$ in 2050.

Most of the cost-effective climate change mitigation potential lies in LMICs, but these regions face technical and financial capacity and resource constraints to utilise the potential. Immediate, ambitious, and collaborative actions are critical to align global emissions with climate goals. Enhanced renewable energy deployment, reduced reliance on fossil fuels, and strengthened international cooperation are pivotal in the cost-effective scenarios. The difference between the regional emission reduction potentials in the cost-effective scenarios and the emission budget allocation under effort-sharing regimes, offers opportunities for voluntary cooperation among countries to achieve their climate targets that align with the principles underpinning Article 6 of the Paris Agreement.

*Brazil*

Emissions are increasing in Brazil under both the Extended Current policies and the Extended NDCs scenarios. The 1.5-degree pathway reaches climate neutrality by 2045 – 2050, and the well-below 2-degree scenario is projected to reach climate neutrality between 2050 and 2060. By 2050, there are significant emission gaps of about 2.3 Gt $CO_2e$ between the policy scenarios and the 1.5-degree pathway, and around 2.0 Gt $CO_2e$ between the policy scenarios and the well-below 2-degree scenario. Brazil's climate targets and policies are also rated as 'Insufficient' by the Climate Action Tracker (2023), meaning they need significant enhancements to align with the 1.5 °C temperature goal. Both the Extended Current policies and Extended NDCs scenarios, as implemented in IMAGE, exceed the fair-share allocation for well-below 2-degree and 1.5-degree budget by the mid-century (see Table 1). Key drivers of emission reductions include rapid electrification, efficiency improvements, and renewable energy expansion, but strengthening the measures post-2030 is essential to meet climate goals.

**Table 1**
Regional annual $CO_2$ emissions in 2050 in various scenarios in Gt CO2

| Region | Regional policy - Extended current policies | Regional policy - Extended NDCs | Cost-effective - Well-below 2 degree | Cost-effective - 1.5 degree | Fair-share - Well-below 2 degree | Fair-share - 1.5 degree |
|---|---|---|---|---|---|---|
| **Brazil** | 1.50 | 1.44 | -0.31 | -0.50 | 0.52 – 1.03 | 0.17 – 0.38 |
| **Indonesia** | 1.03 | 1.61 | 0.0 | -0.36 | 0.79 – 1.50 | 0.27 – 0.58 |
| **South Africa** | 0.45 | 0.09 | 0.13 | 0.0 | 0.16 – 0.23 | 0.05 – 0.11 |
| **Western Africa** | 1.88 | 1.91 | 0.07 | -0.01 | 1.59 – 3.0 | 0.53 – 2.41 |
| **Global** | 37.43 | 30.62 | 10.10 | 2.69 | 23.13 – 23.73 | 7.74 – 8.63 |

*Note: The ranges in the fair-share scenarios represent the maximum and minimum values of the three fair-share allocation principles. The pathways for the scenarios are derived from a diverse array of mitigation scenarios found in the IPCC AR6 database. This approach integrates the results from multiple models. The other scenarios depend solely on the output from the IMAGE model.*

### *Indonesia*
In Indonesia, emissions are projected to increase steadily and peak in 2030 under the Extended Current Policies scenario. The Extended NDCs scenario shows slower reduction relative to Extended Current Policies scenario. Yet both pathways fall far short of the well-below 2-degree and 1.5-degree targets, leaving an emissions gap of 1.1 – 1.5 Gt $CO_2e$ in 2050. Under the Extended Current Policies scenario, emissions stay within the 2.0 °C fair-share budget but surpass the 1.5 °C allocation by mid-century. The Extended NDCs scenario exceed the fair-share allocation for 2 °C budget by mid-century. Cost-effective scenarios show emissions peaking by 2025 and achieving climate neutrality between 2055 and 2070 through rapid electrification, deforestation reduction, and fossil fuel phaseout. Strengthened policies, including forest conservation and clean energy transitions, are critical to meeting climate commitments.

### *South Africa*
Under the Extended Current Policies scenario, South Africa's emissions remain stable but far from 1.5 °C and well-below 2 °C targets. The Extended NDC scenario projects a 70% reduction by 2050 relative to 2020, aligning with the 2 °C fair-share budget but falling just short of the 1.5 °C goal. While the emissions pathway for the Extended NDCs scenario is close to the fair-share allocation for a 2 °C budget, the Extended Current Policies remain higher than the fair-share allocation for both 2 °C and 1.5 °C budget. Transitioning to renewables, enhancing efficiency, and deploying CCS are key strategies. Achieving climate neutrality, as per the conditional NDCs, require accelerated decommissioning coal plants and expanding renewable energy initiatives.

### *Western Africa*
Western Africa's emissions, driven by fossil fuel use, are expected to increase by half by 2050 relative to 2020 under both regional policy scenarios. Emissions are projected to increase by an average annual rate of 1.25% between 2020 and 2050 under these scenarios, remaining within the budgets for 1.5 °C and 2 °C fair-share regimes in the short- and medium-term. Aligning with the cost-effective 1.5-degree or well-below 2-degree pathway requires emissions to peak before 2030 and achieving climate neutrality by 2060 – 2070, closing a 2.0 – 2.2 Gt $CO_2e$ emissions gap between policy scenarios and cost-effective pathways by 2050. Renewable energy and carbon capture and

storage (CCS) play key roles, alongside substantial international support for capacity building and technology transfer.

In conclusion, the differences in emissions between the various scenarios raise important concerns. First, the gap between current policies, NDCs, and the cost-optimal emission pathways challenges the adequacy of current strategies, especially in light of projected climate change impacts. Urgent action is needed to phase down fossil fuels across various scenarios, particularly assessing whether high-income countries are showing sufficient ambition or if increased ambition and international support are necessary. Second, the difference between cost-optimal emissions trajectories and those allocated based on fair-share principles per country raises issues of justice. This situation underscores the potential role of international mitigation finance and the use of Internationally Transferrable Mitigation Outcomes (ITMOs), as described in Article 6 of the Paris Agreement, which allows countries to invest in mitigation efforts abroad. The urgent question remains whether current actions are enough to tackle climate change, given the high emissions levels and the narrowing window of opportunity.

### *The roles of major sectors in emission reduction vary depending on the regional economic structure and the mitigation pathway*

The role of various sectors in climate change mitigation strategies varies significantly depending on the scenarios chosen. Table 2 presents the $CO_2$ emission reduction potentials of various sectors under the scenarios in 2050 relative to 2020. Energy supply, transport, industry, and Agriculture, Forestry, and Other Land Use (AFOLU) are crucial sectors to achieve deep mitigation globally. The growing importance of carbon removal strategies is also evident, as they appear to be increasingly critical to limiting global temperature rise to 1.5 °C. The extent of carbon removal required is contingent upon the speed at which greenhouse gas emissions are reduced across sectors and regions, as well as the degree to which climate targets are exceeded.

Energy supply emissions, including electricity and heat production, fugitive emissions from fossil fuel production, and mining, accounted for a third of the global emissions in 2020. This share is projected to increase slightly by 2050 under the Extended Current Policies scenario but could decrease to 20% under the Extended NDCs scenario. Reducing emissions hinges on accelerating renewables, phasing out coal, and enhancing efficiency, with a potential reduction of 12 Gt $CO_2$ between the Extended Current Policies and the cost-optimal 1.5-degree by 2050. Decarbonising the power sector is crucial for meeting the 1.5 °C or well-below 2 °C targets, especially with rising electricity demand in China, India, and Sub-Saharan Africa. However, LMICs face challenges such as high costs and limited capacity, underscoring the need for international technical and financial support. Transitioning to sustainable energy also offers co-benefits such as job creation, broader energy access, and, in many cases, improved air quality. Overall, while the NDCs, as implemented in IMAGE, show a higher emissions reduction relative to current policies, they only achieve 25% and

20% of the emission reduction required to meet the well-below 2-degree and 1.5-degree targets, respectively.

**Table 2**
Global $CO_2$ emission change in 2050 relative to 2020 under various scenarios (%)

| Sector | Extended Current Policies | Extended NDCs | Well-below 2 degree | 1.5 degree |
|---|---|---|---|---|
| **Energy demand sector (direct emissions)** | | | | |
| AFOLU | -0.2 | +5.3 | -97.4 | -97.0 |
| Bunkers | +90.0 | +41.0 | +37.0 | -19.4 |
| Buildings | -14.3 | -25.1 | -37.0 | -76.1 |
| Transport | -2.2 | -25.6 | -38.1 | -70.9 |
| Industry | +6.1 | -10.4 | -54.2 | -69.3 |
| Other sector | -19.0 | -30.4 | -40.1 | -50.9 |
| **Energy supply sector** | | | | |
| Electricity, heat and hydrogen | -0.2 | -15.6 | -101.1 | -109.5 |
| Fuel extraction and processing (includes biofuels) | -15.1 | -59.2 | -104.2 | -147.6 |
| **Total** | +0.01 | -18.2 | -73.0 | -92.8 |

*Note: The Extended Current Policies scenario and Extended NDC scenario assume equivalent effort (cost-effectively implemented) after 2030 based on the policies and targets implemented before 2030.*

The AFOLU sector is vital for global emission reductions, especially in high-emitting countries such as Brazil and Indonesia, where it currently represents around 50% of total $CO_2$ emissions. By 2050, global $CO_2$ emissions from AFOLU under the cost-effective scenarios are projected to approach carbon neutrality due to increasing carbon sinks resulting from declining deforestation and increasing afforestation, while emissions under Extended Current Policies remain at the 2020 level. Strategies such as forest conservation, agroforestry, soil carbon management, and sustainable livestock practices can significantly lower emissions while enhancing air quality, food and water security, and rural livelihoods. However, poorly designed measures may harm food security and livelihoods in low-income regions, underscoring the need for careful implementation.

The industry sector is a significant contributor to global emissions, and in the Extended Current Policies scenario, these emissions are expected to remain stable. This stability occurs as mitigation measures and the increased energy demand from population and economic growth effectively cancel each other out. Despite reduced fossil fuel dependency, they remain dominant in the energy mix. Industry emissions decline in the other scenarios. Alternative fuels like hydrogen play a minor role in policy scenarios and in the well-below 2-degree scenario, but its share could grow to 2% in the 1.5-degree pathway by 2050. The hydrogen economy faces challenges like unclear demand signals and delayed incentives, financing barriers, regulatory and license uncertainties, and operational challenges (IEA 2024a). More emissions reduction can be achieved through electrification, green hydrogen integration, improved efficiency, and addressing emissions from oil and gas production, helping decarbonise hard-to-electrify sectors (Edelenbosch, Hof et al. 2024).

The transport sector significantly contributes to global $CO_2$ emissions; its emissions (including indirect emissions) are projected to increase by about 15% under the Extended Current Policies scenario. Major contributors include China, India, USA, and the Middle East, but most of the absolute growth occurs in LMICs in Africa and Asia. International aviation and maritime emissions are expected to double despite partial biofuels and sustainable marine fuels replacement. Cost-effective pathways, especially under the 1.5-degree scenario, show emissions dropping below current levels by 2050 as biofuels, electricity, and hydrogen replace fossil fuels. Strategies like fuel efficiency, low-emission modes, and zero-carbon vehicles reduce emissions and improve air quality, pollution, and resource efficiency, supporting sustainable development goals.

In 2020, buildings contributed 25% of global $CO_2$ emissions (including indirect emissions). Under regional policy scenarios, the share is projected to remain stable despite increased energy demand due to improved energy efficiency improvements, greater reliance on electricity over fossil fuels, and decarbonisation of electricity production. Enhancing these measures could cut emissions by 80% and 100% by 2050 relative to 2020 in the well-below 2-degree and the 1.5-degree scenarios, respectively. While the focus of high-income regions is renovating and decarbonising existing large building stock, low- and middle-income regions will have to avoid lock-in by increasing innovation in building low-emission houses and offices for the rapidly increasing new building stocks.

*Brazil*

The AFOLU sector is Brazil's largest $CO_2$ emitter, primarily due to deforestation, but emissions are projected to decline significantly by 2050 in the Extended Current Policies scenario due to reforestation and forest management. Agriculture also contributes nearly a third of total GHG emissions in 2020, with enteric fermentation being a major source. Recommended mitigation strategies for the sector include dietary change and selective breeding to reduce $CH_4$ emissions (de Haas, Veerkamp et al. 2021). The industry sector is projected to significantly reduce emissions by transitioning to electricity, biofuels, and hydrogen, alongside strong energy efficiency measures. The transport sector, the second-largest emitter in 2020 at 20%, is projected to see emissions decrease in absolute terms with increased use of ethanol and electricity. While electricity production and buildings have minimal emissions, their shares are projected to grow modestly by mid-century.

*Indonesia*

In Indonesia, the AFOLU sector was the largest emitter in 2020, accounting for nearly 65% of $CO_2$ emissions that year, driven by agriculture expansion and logging. Its share is projected to decline substantially by 2050 under the Extended Current Policies scenario, while emissions from industry, transport, and buildings are expected to rise. AFOLU is pivotal to the country's effort for emissions reduction, with emissions projected to drop by 70% by 2050 in the Extended Current Policies scenario, and an additional 20% in the 1.5-degree scenario. Industry and transport sectors could contribute to 60% of $CO_2$ reductions by 2050 between the Extended Current Policies and the 1.5-degree scenarios. Electricity consumption is projected to slightly decrease, with emissions from electricity production becoming net negative just after 2040 in the 1.5-degree scenario, aiding in reducing emissions across sectors. Electrification is crucial for GHG reduction, though competition among fossil fuels, hydrogen, and electricity persists, with hydrogen expected to dominate heavy transport under the 1.5-degree scenario.

*South Africa*

South Africa's energy system relies heavily on coal, though there are initiatives that aim to phase out coal and attract climate finance, such as the Just Energy Transition Partnerships. Electricity consumption, particularly in industry and buildings, is expected to double between 2020 and 2050, while coal dependency for power generation is expected to drop from 90% in 2020 to 20% under the well-below 2-degree scenario and 1% in the 1.5-degree scenario. Total $CO_2$ emissions in industry and buildings are projected to rise, remaining stable in transport. Meanwhile, AFOLU $CO_2$ emissions are projected to increase by 5% under Extended Current Policies but become a net sink in the cost-effective scenarios.

*Western Africa*

In 2022, *Nigeria* ranked highest in $CO_2$ emissions from transport and oil production in West Africa, while *Senegal's* industry sector was also a major emitter. AFOLU emissions represent around 50% of total $CO_2$ emissions in 2020, with Nigeria emitting 6 Mt $CO_2$ compared to around 200 Mt $CO_2$ for the region (Friedlingstein, O'Sullivan et al. 2025). Gas flaring remains a significant challenge, but Nigeria has pledged to eliminate it by 2030. Both countries prioritise renewable energy, setting ambitious targets for solar, wind, and hydro, though Nigeria faces policy inconsistencies and Senegal struggles with affordability. By 2050, emissions from transport, industry, and fuel production are projected to decline significantly under cost-effective scenarios, with AFOLU emissions approaching zero due to reforestation. Both countries also focus on forest conservation and restoration to address deforestation and land degradation.

### *It is essential to scale up climate mitigation financing to effectively limit global temperature increases and mitigate associated damages*

The gap between the accumulated policy costs (the net costs of measures to reduce greenhouse gas emissions) of the Extended Current Policies and the 1.5-degree scenario amounts to over USD 50 trillion in 2050 and USD 340 trillion by 2100. The accumulated policy costs differ by region as shown in Figure 2. Under the Extended NDCs scenario, most of the costs occur in North America and Europe, while the largest cost requirements in the cost-effective mitigation scenarios are in East and South Asia, and Sub-Saharan Africa. Benefits (avoided damages) start to outweigh the costs of mitigation at a global scale already by 2030 in the well-below 2 °C scenario, by 2050 in the 1.5 °C scenario, and by 2060 in the NDCs scenario. After 2060 the avoided damages under the well-below 2 °C and 1.5 °C pathways start to rise fast until the end of century while the mitigation costs start to slow down. On an annual average, the policy costs in the 1.5-degree scenario make up about 2.2% of the global average GDP between 2020 and 2050. The 2030 conditional NDC pledges offer a strong basis for further strategies to meet the Paris Agreement.

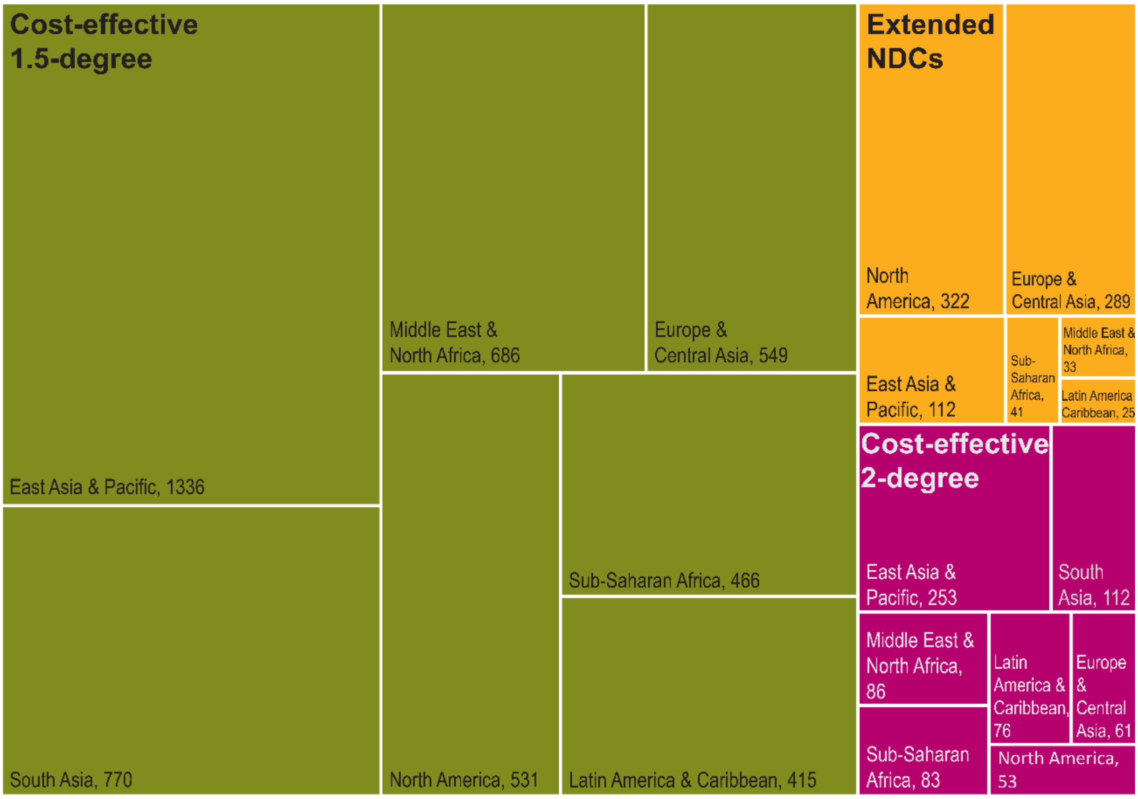



**Figure 2**
Cumulative regional policy costs in 2050 under the Extended NDCs, well-below 2-degree, and 1.5-degree scenarios in billion USD

*Note: These estimates are based on a constant discount rate of 10%.*

From our analysis, the AFOLU sector appears to be a major investment focus for regions like Brazil and Indonesia due to its potential for cost-effective emission reductions through land-use changes. Electrifying industry and transport is crucial for ambitious mitigation in countries like Indonesia and Senegal. Similarly, accelerating the phase-out of fossil fuels, especially coal and oil, is an important strategy, particularly in South and Western Africa. Identifying renewable or low-carbon energy technologies is key here. For Senegal and Nigeria, the evolving energy system and grid offer an opportunity for a comprehensive shift to renewable energy, minimising stranded fossil assets, and enhancing the cost-effectiveness of renewable energy projects.

The policy cost gap is especially evident in LMICs, where limited access to affordable funding hinders the adoption of low-emission technologies. Scaling up climate finance is crucial to deploy renewable energy, improve efficiency, and invest in green hydrogen, CCS, and nature-based solutions. Without substantial increase in climate finance and access to affordable finance, LMICs risk being locked into carbon-intensive development paths, making it challenging and expensive to reverse climate impact. Increased climate mitigation finance is also critical to address equity concerns. LMICs, which are often the most climate-vulnerable, require substantial funding to pursue low-carbon development without compromising economic growth. Private investment is limited due to policy uncertainty and lack of incentives, but public finance through multilateral funds can help mitigate risks and attract private capital.

### *The projected global emissions and mitigation investment requirements are influenced by future socio-economic developments*

The projected emission gap and the associated mitigation costs are influenced by future socio-economic uncertainties. To explore the potential uncertainty range, we compare the model results based on two socio-economic projection scenarios: the most optimistic projection (SSP1) and the moderate projection (SSP2). In the Extended Current Policies scenario, fossil fuels continue to play a significant role, particularly in SSP2, where slower growth in renewable energy leads to higher emissions compared to SSP1. SSP1 scenarios emphasise sustainability, leading to lower emissions and an earlier peak followed by a rapid decline in emissions. In the SSP2, Extended Current Policies scenario sees emissions rising continuously over the same period. However, in the cost-effective 1.5-degree scenario, fossil fuels are virtually driven-out of the energy system in SSP1 and SSP2, while SSP2 requires additional renewable capacity to meet the higher primary energy demand.

SSP1 achieves faster declines in total $CO_2$ emissions, with electricity emissions dropping rapidly and even turning negative before 2050 and total greenhouse gas emissions halving by the end of the century relative to 2020. In this scenario, both SSP1 and SSP2 experience rapid emissions reductions, though SSP2 must decarbonise more aggressively to offset the high energy needs and slower industrial transitions. The most pronounced difference between the SSP1 and SSP2 1.5-degree projections are the policy costs —SSP1 benefits from lower population growth, reduced energy demand, and greater technological advancements, making climate change mitigation significantly less expensive throughout the century. The current geopolitical climate is characterised by power struggles and nationalism that resembles the worldview described in SSP3. However, the challenges in SSP3, which include limited cooperation, technology advancement, and slow economic growth, hinder efforts to meet the Paris Agreement's temperature goals making the 1.5-degree target improbable.

### *The capital costs of new technologies differ across the world; reducing this gap can improve the cost-effectiveness of climate policy*

Effective climate change mitigation is being hindered by higher cost of capital (interest rates of loans) in low- and middle-income countries compared to richer countries. Our model results show higher renewable energy deployment in the scenario with the fast converging weighted average capital cost (WACC) values around the world compared to the scenario with slow converging WACCs, emphasising how lower financing costs can accelerate the displacement of fossil fuels by renewables like solar and wind, especially in LMICs. The fast convergence scenario shows the highest growth in renewable energy, especially in Brazil and Western Africa due to their solar potential, and increased wind energy in Indonesia. In South Africa, lower discount rates boost biomass and nuclear energy shares in the long term. Lower capital costs have minimal impact in Western Africa where solar, wind, and hydro already dominate the energy system. Although fossil fuels are less sensitive to changes in the cost of capital due to higher operational costs, lower capital costs make renewables more financially viable, leading to a shift away from coal and gas investments. Lower capital costs also facilitate investments in battery storage, smart grids, and hydropower, addressing intermittency challenges.

Decline in regional capital costs lead to a reduction in $CO_2$ emissions from AFOLU, buildings, and transport in Brazil by 2050. Indonesia's building and transport sectors see $CO_2$ emissions drop by up to 30% with converging cost of capital relative to the constant WACC. South Africa experiences $CO_2$ emissions reduction in building and transport by 2050 with the rapid declining cost of capital. Western Africa also sees $CO_2$ emissions decline in AFOLU and transport sectors as discount rates decrease. The benefits of lower discount rate also extend to the policy cost of climate change mitigation with savings ranging from 8% in Brazil to 40% in Indonesia. Lower discount rates are crucial for reducing total costs of climate mitigation efforts, making large-scale investments more financially viable.

It is crucial for bilateral and multilateral collaborations to acknowledge the high cost of capital as a barrier and implement measures to facilitate easier access to affordable finance in LIMCs. Addressing this challenge and increasing investments could accelerate the transition to low-carbon development and help achieve global temperature targets. While direct monetary costs of mitigation are essential, they overlook indirect opportunity costs, which are often harder to quantify. Applying lower region-specific capital costs rather than the current high rates in LMICs could lead to investment decisions that are more oriented towards longer term climate ambitions, and influence the energy generation mix and average electricity prices. Ultimately, the cost of capital—shaped by perceived political and technological risks—plays a pivotal role in determining the overall expense of mitigation efforts.

# FINDINGS

# 1 Introduction

## 1.1 Background

The Paris Agreement aims to limit the global average temperature increase to well below 2 degrees Celsius above pre-industrial levels, while pursuing a more ambitious target of limiting the increase to 1.5 degrees Celsius (UNFCCC 2016). Currently, 195 countries have submitted Nationally Determined Contributions (NDCs) to the Paris Agreement that include domestic climate actions and finance needs (UNFCCC 2024b). Most of the low- and middle-income countries (LMICs) contributed the least to climate change but those are simultaneously the countries that face disproportionately harsh effects from it. Such impacts include droughts, floods, and extreme weather events, to name a few.

There is a growing dilemma of pursuing economic development while simultaneously reducing emissions. Balancing these priorities is challenging, as rapid industrialisation and infrastructure development can lead to increased emissions. Many low- and middle-income countries, such as Brazil, Indonesia, Nigeria, and South Africa, also heavily rely on fossil fuels for energy generation and for major economic activities due to the lack of access to modern, clean energy sources, which also contribute to the growing emissions.

Achieving global climate neutrality requires significant investment in technologies and infrastructure, which remains a major challenge for LMICs (Yilmaz, Alswaina et al. 2023). Several studies (Fankhauser, Sahni et al. 2016, CPI 2023b) already show that there is a significant gap in the available and required finance for climate change mitigation in these countries. The growing consensus is that this might deter mitigation activities across the globe, increasing the gap between current emissions and the emission path to reach net zero goals and impacting sustainable development. On the other hand, climate change mitigation measures, such as energy-demand changes through efficiency improvements or lifestyle changes, could reduce the mitigation costs (Fujimori, Oshiro et al. 2023).

Yilmaz, Alswaina et al. (2023) report that low- and middle-income countries face higher exposure to transition risks than high-income countries given their reliance on carbon intensive sectors and limited access to affordable finance. It is important to recognise that addressing the shortfall in emissions reductions needed to meet targets and associated costs in LMICs is a complex and long-term endeavour that requires collaboration between governments, international organizations, the private sector, and civil society. Adequate support, equitable allocation of emission reduction obligations, and a holistic approach to sustainable development and climate action are essential components of any strategy to tackle these challenges.

Limited technological and financial resources in many countries can hinder their ability to adopt and implement clean energy technologies and practices, further contributing to the emission gap. These countries face a significant gap in funding for climate change mitigation and adaptation efforts. This includes investments in renewable energy, sustainable agriculture, and resilience-building initiatives (CPI 2023a, Montague, Raiser et al. 2024). The international community, including high income nations, has committed to providing climate finance to support low- and middle-income countries in their climate action efforts. However, there have been challenges in meeting these commitments. These nations often encounter difficulties in accessing climate finance due to complex application processes, inadequate institutional capacity, and regulatory barriers (Wags Numoipiri and Ifeanyi Onyedika 2024).

This report is structured into six chapters. *Chapter 1* introduces the study by providing essential background information, outlining the justification for the research, and stating its objectives and research questions. *Chapter 2* details the methodological framework, describing the methods and tools used, including scenario analysis, the model employed, sensitivity analysis, and profiles of the focus countries or regions. In *Chapter 3*, the report delves into theoretical aspects, discussing NDCs, climate damages, and climate finance. *Chapter 4* presents the empirical results, showing emission trends across various scenarios, the roles of key sectors within these scenarios, and projections of climate damages and policy costs. *Chapter 5* focuses on sensitivity analysis, examining how socio-economic projections and varying costs cost capital impact the results. Finally, *Chapter 6* offers a reflection on the implications of the different scenarios for policy development and the justice dilemma concerning the NDCs.

## 1.2 Justification

Mitigating climate change requires immediate and ambitious action. An effective strategy to tackle climate change requires identifying and prioritising the high impact mitigation sectors. Resources of governmental and non-governmental development agencies are limited, and the impact of climate change is already being felt. Hence, climate change mitigation strategies need to be strategically designed and expertly implemented while simultaneously fostering human development in low- and middle-income countries. Understanding the high impact sectors and actions is crucial for the efficient use of limited resources.

The Directorate-General for International Cooperation (DGIS) requested this assessment to identify emission gaps between current policies, NDCs and other climate-change mitigation pathways, which sectors offer the largest mitigation potential, and identify associated costs to meet climate change mitigation commitment in priority countries and regions.

## 1.3 Objectives and research questions

Pursuant to the request from DGIS, this study sets out to evaluate how well announced policies align with climate change mitigation commitments and compare them to cost-effective pathways and regional 'fair shares' projected by Integrated Assessment Models to underscore the importance of collaborative efforts. Furthermore, we seek to identify the additional financial resources required to address gaps in both implementation and ambition. We will explore which sectors offer mitigation potential according to current policies, the NDCs, and the cost-effective pathways. The analysis helps identify the gaps between government policies, projected cost-effective pathways, and fair-share allocations. It also offers insight into the financing needs to achieve the climate change mitigation targets. The financial requirements are technology-related investments and will not cover investments related to adaptation, capacity-building, and policy implementation costs, which might increase the investment requirement significantly.

To meet the objectives of the study, we formulate five research questions to (i) explore the emission paths of various scenarios, (ii) explore the role of sectors and technologies in emission reduction and related investments, and (iii) reflect on the policy implications for the focus regions. We also look at the sensitivity of these results for change in socio-economic projections and regional investment risks (see Chapter 5). Hence, the research questions are:

1. How large is the emission gap between the current policies, the regional NDC ambitions, the cost-effective mitigation pathways, and Effort-share emission allocations?
2. What roles do policy interventions in major sectors play in emissions reduction under various scenarios?
3. What are the policy cost implications under various scenarios?
4. How are these results influenced by socio-economic projections and specific investment risks in LMICs?
5. In the context of these results, what is the priority measures in the selected focus regions?

# 2 Methods and tools

This chapter outlines the model applied, the scenarios explored, the sensitivity analysis conducted, and the selected country profiles included in the study. Central to the analysis is the IMAGE Integrated Assessment Model framework that simulates the potential impacts of various pathways on major economic sectors, various technologies, and related GHG emissions. A sensitivity analysis was performed to assess how changes in key assumptions, such as on socio-economic developments and the cost of capital, affect the model's outcomes. This section also presents the profiles of the focus countries for this study.

## 2.1 The IMAGE model

The main tool used in this study is the IMAGE modelling framework, complemented with results from other studies where necessary, for instance to emphasise certain country's roles in a regional context. IMAGE is a powerful tool to explore the interaction between society, the biosphere, and the climate system to assess sustainability issues such as climate change and biodiversity. The IMAGE core model includes a detailed description of the energy, land-use and plant growth, carbon and water cycle systems. The IMAGE framework integrates several soft-linked and specialised models to address diverse environmental and policy challenges. These include the agro-economic model MAGNET, the policy and impact model FAIR (climate policy), and the biodiversity model GLOBIO. Together, these models provide a comprehensive system for analysing interactions among economic, environmental, and societal processes (PBL 2024a). With this framework we are able to do simulations in yearly timesteps between 1970 and 2100 for 26 world regions (see Figure 3 for regional groupings).

TIMER, the energy model of IMAGE, describes demand and supply of key energy carriers (van Vuuren, van Ruijven et al. 2006, PBL 2024a). The model addresses key issues such as transitions to sustainable and modern energy systems, improving energy access, future energy demand projections, exploring the role of the energy conversion sector and various energy technologies in promoting sustainability. Market shares of technologies are determined using perceived costs of different options with a multinomial logit allocation. It thereby assigns the largest market share to the cheapest energy technologies, while technologies that have higher costs get lower shares, considering heterogeneous local characteristics where relevant. The discount rates, which reflect the regional investment risks, play a key role in determining the annualised capital costs of a given technology. TIMER also calculates greenhouse gas emissions associated with energy consumption and energy conversion processes, providing insights into strategies for mitigating climate impacts.

The IMAGE-Land model simulates agricultural land use, natural land cover, forestry, and livestock systems on a high-resolution grid with a spatial detail of 5 arc minutes. This granularity enables precise analysis of land-use dynamics and their interactions with environmental and socio-economic factors. IMAGE-Land is also used to allocate land required for bioenergy production after the demand is determined in TIMER (Doelman, Stehfest et al. 2018).

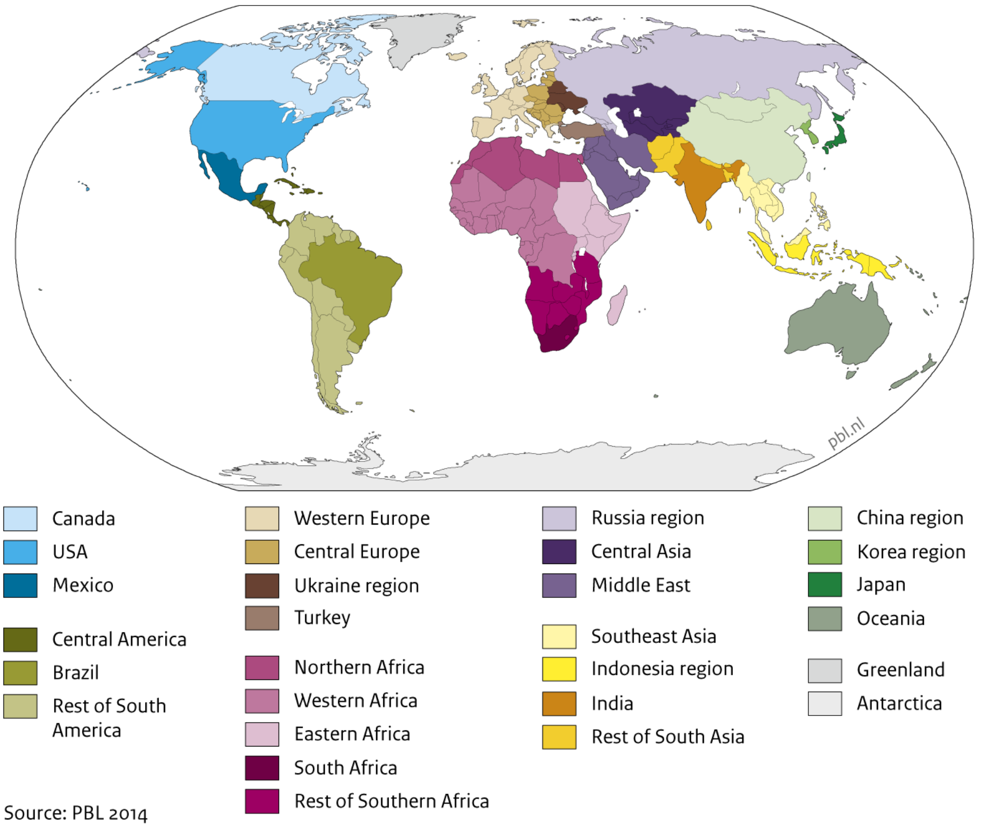



**Figure 3**
The 26 world regions of IMAGE (PBL 2024a)

The results of IMAGE are complemented with desk studies for a deeper analysis in priority countries within IMAGE regions. Secondary data has been collected from country-focused studies and analysed to find parallels with the regional results of IMAGE on development of these priority countries.

## 2.2 Scenarios

Scenarios are detailed narratives that outline plausible future events and illustrate the pathways leading to particular outcomes. They have become an essential tool in policy formulation processes, aiding in the identification of potential solutions to policy challenges by exploring a variety of available options. Scenario analysis provides a framework for visualising, rehearsing, and testing the acceptability of different strategies, thereby helping policymakers understand and manage complex uncertainties (Volkery and Ribeiro 2009).

In this study, we examined three sets of scenarios and variants of such scenarios to explore the sensitivity of the results to changing assumptions on investment risks and socio-economic projections. The analysis is based on the set of the Shared Socioeconomic Pathways (SSP) that consist of five distinct global socio-economic pathways (SSP1 – SSP5) describing the future evolution of key aspects of society that together imply a range of challenges for mitigating and adapting to climate change (Riahi, van Vuuren et al. 2017, van Vuuren, Riahi et al. 2017). Our main scenarios are based on SSP2 that describes a world where social, economic, and technological trends follow 'the middle of the road' path and do not shift markedly from historical patterns as implemented in IMAGE (van Vuuren 2021). Table 3, Table 4, and Table 5 present the main characteristics of the scenarios.

The first set of scenarios (see Table 3), the regional policy scenarios, are used to determine the impact of existing and planned climate policies on emission levels and the resulting temperature change in 2100 relative to pre-industrial levels. The regional policy scenarios include the Extended Current Policies scenario and the Extended NDC scenario. Under the Extended Current Policies scenario, the current climate policies as of June 2022 covering the period up to 2030 for each country are taken into account (see Appendix 3 for the scenario protocol and the polices that are covered) (Dafnomilis 2024, Dafnomilis, den Elzen et al. 2024). The Extended NDC scenario explores the impact of NDC pledges of countries on emissions mitigation and global temperature increase. These scenarios are based on the work of den Elzen, Dafnomilis et al. (2023). These NDC policy measures are extrapolated beyond 2030 by equivalent carbon price by applying the GDP growth rates of various regions based on the methodology by van Soest, Aleluia Reis et al. (2021). This extrapolation is primarily illustrative.

**Table 3**
Regional policy scenarios description

| Scenario | Scenario ID | Characteristics | Model implementation |
|---|---|---|---|
| Current policies scenario, extended beyond 2035 | Ext_CurPol | As reference scenario, including implementation of current domestic policies (cut-off date May 2021), the socio-economic projections are based on SSP2. | The existing climate policies are set to be in effect until 2030. The year 2030 was selected as it aligns with the target year for nearly all policies included in the IMAGE model. After 2030, it is assumed that policies will remain unchanged, with sector-specific policy goals upheld at the current levels where applicable. All sectoral carbon prices, fuel prices, subsidies, and power production premiums will be maintained at the current levels through the end of the century. Policies with specific target levels for particular years, such as renewable capacity targets for power supply technologies, are considered minimum thresholds within the model. Therefore, if the model's endogenous solution in the post-2030 period results in a more ambitious outcome than current policies, the model will adopt the enhanced outcome. |
| NDCs scenario, contributions extended beyond 2030 | Ext_NDC | Builds up on the Ext_CurPol scenario including implementation of NDC until 2030, following the post-2030 extension guidelines thereafter, socio-economic projections based on SSP2. | For each country, target emission levels as submitted in their conditional NDC is implemented, the carbon price aligned with the NDC trajectory is kept constant until the 2100. |

The second set of scenarios, the cost-effective scenarios, are used to determine the role of various sectors and regions in mitigating emissions towards a 1.5 °C or well-below 2 °C global mean temperature change target by 2100. In these scenarios, the global temperature targets are achieved by determining a global carbon price that is required to meet the target and mitigation actions are implemented when marginal costs are lower than this carbon price, assuming some level of global coordination (Riahi, Bertram et al. 2021). The regions and sectors with the cheapest mitigation cost get assigned the highest reduction in emissions, while the regions and sectors with the highest mitigation cost gets the lowest share of the global emission reduction to reach a certain climate target. This approach does not reflect the regional economic or social priorities, the fairness of emission budget allocation, the responsibility for historic emissions, or the techno-economic capability of regions to attain these targets. See Table 4 for scenario description.

**Table 4**
Cost-effective scenarios

| Scenario | Scenario ID | Characteristics | Model implementation |
|---|---|---|---|
| 1.5-degree scenario | CostEff_15D | Model projected cost-effective scenario to limit global temperature increase to 1.5 degree above pre-industrial level by the end of the century with 50% probability, socio-economic projections based on SSP2. | Economy-wide carbon price to keep temperature increase to well-below 2 degree Celsius. |
| Well-below 2.0-degree scenario | CostEff_20D | Model projected cost-effective scenario to limit global temperature increase to well below 2.0 degree above pre-industrial level by the end of the century with 66% probability, socio-economic projections based on SSP2. | Economy-wide carbon price to keep temperature increase to below 2 degree Celsius. |

The third set, effort sharing scenarios, explore the share of regional emissions based on fairness principles. There is a wide variety of effort-sharing approaches in the literature (see (Pan, Elzen et al. 2017, Davide, Parrado et al. 2018, van den Berg, van Soest et al. 2019)). In this study, the fair share principle takes into consideration aspects of physical and social uncertainties, global mitigation strategies, and equity considerations under a certain global emission budget that is compatible with a maximum temperature increase of 1.5 °C and well-below 2 °C above pre-industrial levels. Physical uncertainties primarily arise from uncertainties in the Earth's temperature response, which significantly influence the remaining carbon budget, thereby impacting both global and national emission trajectories. Variations in global strategies for achieving the Paris Agreement climate goals include temperature targets, the timing of mitigation efforts, and assumptions about negative and non-$CO_2$ emissions. The third dimension addresses the normative aspect of equitably distributing efforts to achieve climate goals, guided by fairness principles such as responsibility, capability, and equality. These fair share scenarios should not be seen as a mere moral priority but include a wide range of factors and represent a practical and pragmatic path to collectively achieving global climate ambitions (see Appendix 1 for more on the methodology). Assessment of the fairness of these principles varies according to the interests of the stakeholder and their worldview. Our scenarios are based on the scientific work done by Dekker, Hof et al. (2025) and are only used to put the results of the policy and cost-effective scenarios in the context of fair-share discourse. For comparison and context, we present the fair-share regime coverage by taking the minimum and the maximum national/regional values from the various fair share allocation principles. The scenario description is summarised in Table 5.

**Table 5**
Effort sharing scenarios ( for 2 °C and 1.5 °C with 50% probability and a slight overshoot)

| Scenario | Scenario ID | Characteristics |
|---|---|---|
| Per capita convergence | PCC_20D and PCC_15D | Equality is the primary principle, starts by keeping current fractions of emissions for countries constant while all countries decrease emissions proportionally, then over time (varies by region) the emission allocations converge to the proportion of the projected population. |
| Equal cumulative per capita | ECP_20D and ECP_15D | With responsibility and equality as primary guiding principles, Future emissions are allocated in proportion to the current population, with adjustments made to account for historical emissions that exceeded proportional levels. |
| Ability to pay | AP_20D and AP_15D | Capability is the primary equity principles, emission allocation is determined inversely relative to GDP per capita fraction, considering increasing costs of marginal abatement. |

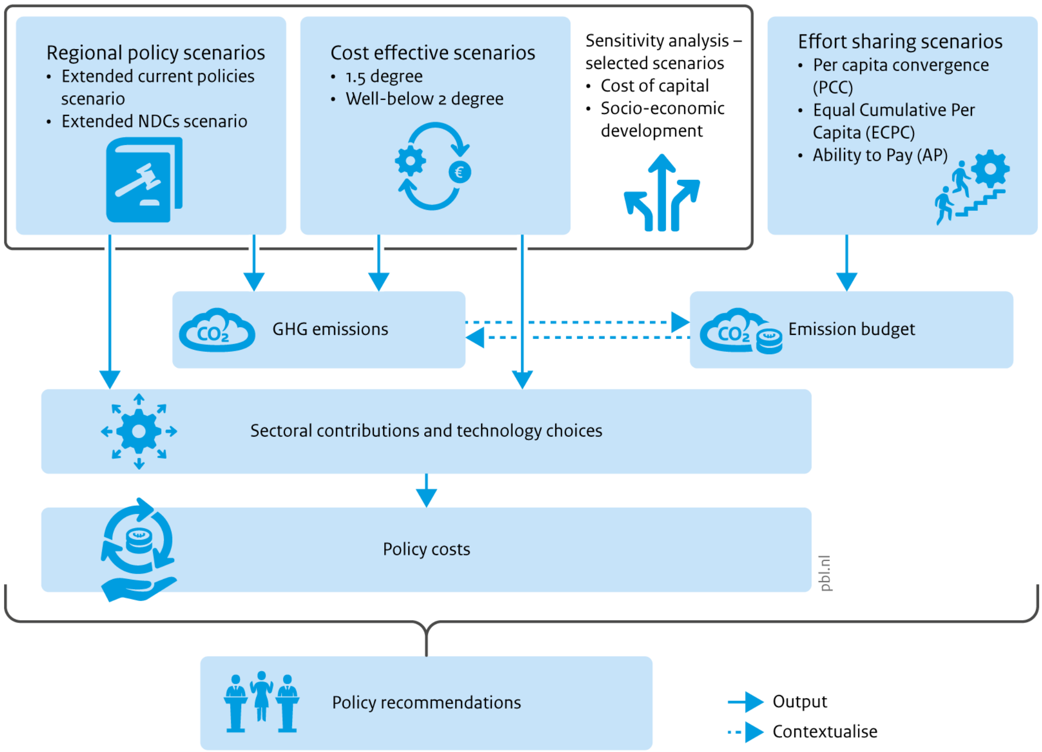
The choices in the scenario construction will determine the technologies that will play a role in reducing emissions. While in the regional policy scenarios, the shares of various sectors in emission reduction are predetermined, the cost-effective scenarios let the market/costs determine the share of different technologies in reducing emissions, with the technologies with the highest potential at the lowest cost playing the main role.

These scenarios share the same socio-economic assumptions based on the Shared Socio-economic Pathways (SSPs), specifically SSP2, also referred to as the middle-of-the-road scenario (Riahi, van Vuuren et al. 2017). Under this scenario, the global population is projected to reach 9.3 billion in 2050, a 21% increase relative to 2020. The global economy is projected to grow two-fold between 2020 and 2050, which is an average annual growth rate of 2.8% in that period. In our model, the investment requirements of climate change mitigation under these scenarios are determined based on the cost of the technologies and the weighted average cost of capital.

Total mitigation costs in the IMAGE model are estimated via the Marginal Abatement Cost (MAC) curves, that show which measures are needed to meet an emission reduction target and the associated costs. The total abatement costs include the costs of all measures that are not exceeding the marginal cost limit. Total mitigation costs include both energy- and land-based mitigation costs covering all economic and AFOLU sectors. These costs ultimately depend on the assumptions about the availability of additional mitigation measures and the cost development of various emission abatement technologies.

Figure 4 presents the analytical framework of the study. As can be seen in the framework, the first two sets of scenarios are used for determining the projected emission levels, subsequent sectoral technology choices, and related policy costs, while the third set of scenarios are used to put these results in the context of regional emission budget compatible to a certain temperature target allocated based on fair-share principles. The technology choices and policy costs are affected by various factors including the cost of capital and future socio-economic development. These impacts will be explored in the sensitivity analysis.

**Analytical framework**




Source: PBL

**Figure 4**
The analytical framework of the study

# 2.3 Sensitivity analysis

There are several factors that could influence the short-, medium-, and long-term impact of our scenarios. There is literature on the role of variations in socio-economic projection (Riahi, van Vuuren et al. 2017) and the cost of capital (Donovan and Corbishley 2016) in how emissions could change in the future and its impact on associated financial requirements. Two sets of scenarios will be analysed to explore the sensitivity of the results to socio-economic changes and weighted average cost of capital.

For the former, we will look at a variation of socio-economic projections in the SSP framework and explore the SSP1 projections of population increase, economic growth, urbanisation, trade, energy, and agricultural systems. While taking SSP2 as the main scenario for our analysis, SSP1 (lower challenge) offer divergent perspectives in the context of challenges to climate change mitigation and adaptation. SSP1 provides the most optimistic pathway for human development and environment. The scenario highlights significant advancements in global education, healthcare, and poverty reduction, along with a decline in global inequalities. Refer to Table 6 for a description of each scenario.

**Table 6**
Sensitivity scenarios for socio-economic development

| Scenario | Scenario ID | Characteristics |
|---|---|---|
| Current policies scenario under SSP1, extended beyond 2035 | ExtCurPol_SSP1 | As reference scenario, including implementation of current domestic policies (cut-off date May 2021), the socio-economic projections are based on SSP1 |
| SSP1 projections with cost-effective 1.5 °C target | CostEff_SSP1 | Model projected cost-effective scenario to limit global temperature increase to 1.5 degree above pre-industrial level by the end of the century with 50% probability, socio-economic projections based on SSP1 |

The later set of scenarios addresses the role of cost of capital and perceived investments risks in low- and middle-income countries based on the study by Calcaterra, Aleluia Reis et al. (2024). Climate change mitigation efforts largely rely on private sector investment where investment decisions are driven by the market rate of return. To get a realistic and accurate representation of future finance gaps towards any climate target, the cost of capital is a crucial metric. The role of financing conditions has only recently been captured more realistically in the analysis of countries' mitigation pathways. As with any other investment project, the measure most used to display financing conditions is the weighted average cost of capital (WACC). Depending on the perspective in private investment decisions, it is reflecting the relative risk rate of the project or the expected rate of return of investment. In broad terms, it is composed of the risk-free rate plus a country premium and a sector- or technology-specific rate, leading to vastly different WACC measures across energy technologies and especially across various countries. As such, WACC measures have a higher impact for clean, renewable energy technologies compared to conventional fossil fuel technologies due to their high upfront capital requirements (IEA 2024b). In addition, the country risk premium factor adds a significant burden and resistance to low- and medium-income countries as it represents geopolitical, structurally economic, and institutional factors that explain the riskiness of investments in a particular country. Hence, taking these factors into account is crucial for more factual investment analysis but also puts developing countries at the higher end of WACC range. To explore these variations, we explore the impact of (a) region specific WACCs that converge to the USA and EU WACCs by the year 2050 on sector mitigation potential, and (b) region-specific WACCs that converge to the USA and EU WACCs a century later (by the year 2150), technology choices, and policy cost (see Table 7 for the summary of the scenario description). Country level WACC values have been based on the study by Calcaterra, Aleluia Reis et al. (2024) with two modifications:

- Technology premiums have been removed (Equation 3 and Equation 4 in Calcaterra, Aleluia Reis et al. (2024)) in order to obtain country wide WACC values.
- Instead of a company specific debt share, a 60% debt share has been applied to all countries (Equation 1 in Calcaterra, Aleluia Reis et al. (2024)).

**Table 7**
Sensitivity scenario for Weighted Average Cost of Capital

| Scenario | Scenario ID | Characteristics |
|---|---|---|
| Average country/region discount rate in SSP2 | FastConv_WACC | Country-specific WACC is implemented reflecting perceived investment risks in the short term, the WACC converges to high-income countries (specifically, EU and the USA) by 2050, socio-economic projections based on SSP2 |
| Average country/region discount rate in SSP2 | SlowConv_WACC | Similar to the above but converges a hundred years later by 2150, socio-economic projections based on SSP2 |

## 2.4 Country profiles

Given the limitation of the regional aggregation in our integrated assessment model, there are only a few individual countries that we can explore. Others are aggregated to the relevant regional cluster. The focus regions/countries, as selected in consultation with the Dutch Ministry of Foreign Affairs, are Brazil, Indonesia, South Africa, and Western Africa (with particular attention to development in Nigeria and Senegal).

The Netherlands is a major player in the development cooperation arena. The Dutch development cooperation takes different forms depending on the level of development of the country and its priorities. In this context, there are a growing number of countries where the Netherlands is engaged in trade and development cooperation, focusing on sustainability and digitalisation. The countries selected for this study also fall in this category where trade and development cooperation activities are combined. Figure 5 presents the sectoral GHG emissions in 2020 for the focus countries.

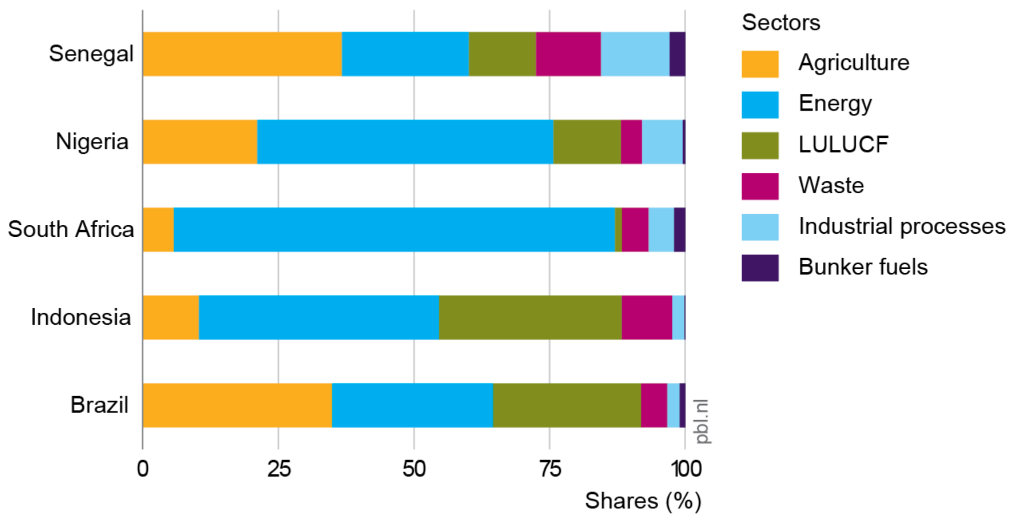



**Figure 5**
Sectoral GHG emission by country in 2020

***Brazil***

Brazil is the largest country in South America both by land mass and population size. Brazil's GDP was USD 2364 billion PPP (constant 2010 USD) in 2020 that is projected to grow to USD 4580 billion PPP (constant 2010 USD) in 2050. The total population in 2020 was 214 million and it is projected to reach 235 million in 2050 under the SSP2 scenario. The country has a diverse economy characterised by agriculture, mining, manufacturing, and services. It is home to a substantial portion of the Amazon rainforest, a critical carbon sink. Land-use, land-use change, and forestry (LULUCF) emissions have been amongst the largest source of GHG emissions in Brazil, as shown in Figure 5. Preventing and combating deforestation in one of the biggest challenges the country is facing. The government Action Plan to Prevent and Combat Deforestation in the Legal Amazon targets zero deforestation by 2030. The success of the country's NDCs hangs on halting deforestation and extensive reforestation and restoration on native forests (Climate Action Tracker 2023). Looking at the sectoral breakdown of energy-related $CO_2$ emissions in 2022, the transport sector contributes more than half of the total emissions (51.4%), followed by industry (21.6%) and electricity & heat production (12.2%). The residential, commercial, agriculture, and other energy industries contribute the remaining emissions (IEA 2023a). The country also aims to achieve climate neutrality by 2050.

### *Indonesia*

Indonesia is a country in Southeast Asia. It has the region's largest economy and the world's fourth largest population. The population is projected to peak at 308 million in 2050 from the current 277 million under the SSP2 scenario. The GDP is projected to grow by 250% in 2050 relative to 2020 under this scenario. It has a rapidly growing economy driven by agriculture, manufacturing and service sectors. Its importance in climate change mitigation is underscored by the country's role as a major producer and consumer of fossil and renewable energy (IEA 2023a). Its oil imports have also increased rapidly in recent years. In 2022, coal contributed 36.4% of the total energy supply, followed by oil (28.1%), natural gas (12.7%), and renewables that include hydro, wind, solar and biofuels. Coal has been the major source of electricity in the country and a major obstacle to the country's climate efforts. Coal accounted for 57.5% of total $CO_2$ emissions from fuel combustion in 2022, followed by oil (32.9%) and natural gas (6.5%). From a sectoral perspective, electricity and heat production accounts for 45.5% of total energy related $CO_2$ emissions, followed by industry (24.6%) and transport (22.5%). At the same time, over the last 20 years, land-use, land-use change, and forestry emissions accounted for over half of the total emissions in Indonesia. The efforts to reduce annual tree coverage loss is showing a positive result as reducing emissions from deforestation is an important part of the country's climate action (Climate Action Tracker 2023). Based on a set of political, geographic, and social factors, (Chen, Noble et al. 2024) rank Indonesia as the 97th most vulnerable country to climate change impacts out of 181 countries.

### *South Africa*

South Africa is the second largest economy in Africa after Nigeria. Under the SSP2 scenario, the population of South Africa is projected to grow from 58 million in 2020 to 66 million in 2050. Similarly, the GDP is projected to grow two-and-a-half-fold, from USD 357 billion (2010) in 2020 to USD 877 billion in 2050, an average annual growth of over 3%. It has a well-developed financial and industrial sector, while the key economic sector also includes mining, agriculture, manufacturing, and services. South Africa is a major emitter of greenhouse gases in Africa with its heavy reliance on coal for electricity production that accounts for 84% of the installed capacity. South Africa also suffers from a continuous energy crisis that impacted the country's economy as well as households (Climate Action Tracker 2023). Coal accounts for 70.9% of the total energy supply, followed by oil (19.9%), renewables (4.7%), natural gas (2.5%), and nuclear (2%). Coal also accounts for 82.6% of total $CO_2$ emissions from fuel combustion in 2022, followed by oil (16.6%) and natural gas. Looking at the sectoral emissions in South Africa, electricity and heat production are responsible for 57.8% of total energy-related $CO_2$ emissions, once again affirming the dominance of coal in the energy system in South Africa. Transport (12.1%) and industry (11.6%) are also accountable for most of the energy-related $CO_2$ emissions in the country (Climate Action Tracker 2023). South Africa's current climate policy ambition is focusing on the decarbonisation of its fossil-fuel sector up until 2030 which accounts for 80% of its total GHG emissions. Beyond that, other sectors are planned to increasingly be coupled to this transition i.e. fostering low-emission vehicles in transport next to hard-to-abate sectors such as industry and buildings (de Aragão Fernandes 2023). In addition, South Africa's NDC mentions just transitions considerations for its mitigation pathway that includes labour reskilling, diversification of coal regions, and support to new green sectors, among others.

### *Western Africa*

The Western Africa region includes Nigeria and Senegal together with other countries[1] and has a population of over half a billion people in 2020. The region is projected to increase to over a billion by 2050 (covering half the total population of Sub-Saharan Africa) under SSP2. The economy is also projected to grow at an average annual rate of 5.7% between 2020 and 2050.

*Nigeria* is Africa's most populous country and its biggest economy. As the richest oil resource centre of the African continent, Nigeria's economy heavily depends on oil and gas export that account for nearly 90% of its export earnings and a significant share of government revenue. It is also the largest gas consumer in Western Africa. Yet, total energy supply in Nigeria is dominated by biofuels and waste that account for 43.44% in 2022. Oil and natural gas together account for 54.4%, while coal and hydro (1.1% each) provide the rest. Oil is the largest source of $CO_2$ emissions in Nigeria, accounting for 66.6% of total emissions from fuel combustion. Natural gas accounts for 30.1% and coal for 3.3% of total $CO_2$ emissions from fuel combustions. While looking at the sectors, transport is by far the biggest emitter accounting for 60.5% of total energy related $CO_2$ emissions int he country. Electricity and heat production account for 14.9%, followed by industry with 10.7% (IEA 2023a). Nigeria is modelled as part of the western and central Africa region in IMAGE model.

*Senegal* is a country located in the westernmost part of Africa with a population of nearly 18 million, and an average annual growth rate of 2.7% over the period from 2010 to 2023. A quarter of the population lives in the Dakar region. Its economy has been growing steadily over the past 20 years (IEA 2023a). Agriculture is the main economic activity that provides employment to two-thirds of the economically active population. The total energy supply is dominated by oil that accounts for 53.7%. Biofuels and waste play a vital role in energy supply with a share of 34.7% in the energy mix followed by coal (10%), and wind and solar (1.5%). Oil also plays a significant role in electricity production accounting for 77% of the electricity produced. Solar and wind account for 13.1% of the total electricity production in the country. The total emissions from fuel combustion in Senegal in 2022 was just 11.32 Mt $CO_2$, equivalent to what the Netherlands emits in one month. The transport sector is the largest emitter, accounting for 43% of total energy-related $CO_2$ emissions, followed by electricity and heat production (36.6%), industry (14.6%), and residential (5.1%) (IEA 2023a). Senegal is modelled as part of the western and central Africa region in IMAGE model.

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[1] see Figure 4 or Table 11 in Appendix 3 for regional groupings

# 3 NDCs, climate damages, and status of climate finance

This chapter introduces Nationally Determined Contributions (NDCs) as a key instrument of the Paris Agreement, outlining how countries set climate action targets. This section of the report also presents the role of NDCs in climate change mitigation. By examining the frameworks, this chapter underscores the significance of NDCs in driving international climate efforts and highlights the critical financial challenges that need to be addressed to fulfil these commitments effectively. In addition, the chapter discusses the cost of inaction by presenting the projected impact of unmitigated climate change.

## 3.1 Understanding Nationally Determined Contributions

The NDC is a key instrument of the Paris Agreement, where countries pledge their climate action goals for the next ten years, recorded in the NDC Registry. Considering each nation's unique circumstances, these pledges should reflect the principle of common but differentiated responsibilities and respective capabilities (UNFCCC 2016). Collectively, these NDCs should aim to keep the pathway open for limiting global temperature rise to the agreed limits of well below 2 °C or to 1.5 °C. In addition to domestic mitigation objectives and potential supporting measures, the NDCs may also include finance needs and adaptation plans.

Countries are requested to submit and increase the ambition of their NDCs every five years, three years prior to the global stocktake. This stocktake compiles the submitted NDCs, assesses current climate actions, and summarises the global status of climate policy, focusing on how to collectively comply with the long-term temperature limits. The first stocktake occurred in 2023, with the next scheduled for 2028. As a result, countries are required to update their NDCs by 2025, extending their goals to cover the period up to 2035.

Whereas NDCs focus on the short term up to ten years, the Long-Term Strategies (LTS) include long-term goals to align with climate neutrality around mid-century. This goal is included in the Paris Agreement, which states that in order to achieve the long-term temperature goal, countries should aim to reach a balance between emissions by sources and sinks of GHG in the second half of this century (UNFCCC 2016).

In addition to emissions reductions, countries can also indicate finance needs for both mitigation and adaptation. The ‘climate finance needs’ refer to local, national, or transnational (international) financial flows. International finance are flows from high-income to low-income countries. By the time of the Global Stocktake in 2023, approximately 90% of countries had provided information on their financial needs, with around 70% indicating requirements for international finance, and around 45% included quantified information (UNFCCC 2024b). For this purpose, countries often pledge unconditional NDCs that will be implemented without external funding, while conditional NDCs require additional financial support and capacity building.

In general, LMICs face challenges due to structural inequalities and historical disparities that affect their ability to implement ambitious climate commitments. In Section 6.2 further on we discuss how justice considerations could impact the formulation and implementation of NDCs within the context of global climate governance, particularly for LMICs.

## 3.2 The potentials of NDCs in climate change mitigation

The collective progress of NDCs implementation under the Paris Agreement is reflected in the reduction of the projected global temperature increase from an estimated 4 °C shortly before the agreement's adoption to the current range of 2.1–2.8 °C (UNFCCC and CMA 2023). However, they are still not sufficient to stay on a pathway to keep temperature increase well below 2°C or to 1.5 °C by 2030. The projected (median) gap between unconditional NDCs and the 2 °C pathway is 14 Gt $CO_2e$, while it is 18 Gt $CO_2e$ for 1.5 °C pathways in 2030 (United Nations Environment Programme 2024).

The NDC targets for Brazil, Indonesia, Nigeria, Senegal, and South Africa are shown in Table 8. While the emissions reduction target of Brazil is relative to a historical year, these targets for Indonesia, Nigeria, and Senegal are relative to a baseline and for South Africa, they are given in absolute emissions level.

**Table 8**
NDCs targets year for Brazil, Indonesia, Nigeria, Senegal, and South Africa

| Country | NDC<br>Emissions reduction target | Source |
|---|---|---|
| Brazil | Reduce greenhouse gas emissions by 48.4% below 2005 levels by 2025, and 53.1% below 2005 by 2030[2] | (den Elzen, Hof et al. 2014)<br><br>Climate Action Tracker (2023) |
| Indonesia | Reduce emissions by 31.89%, compared to baseline emission projections by 2030<br><br>Reduce emissions by 43.2%, compared to baseline emission projections by 2030<br><br>The business-as-usual (BAU) scenario starts in 2010 with 1,334 Mt $CO_2$eq (including LULUCF $CO_2$), and is projected to reach 2,869 Mt $CO_2e$ by 2030 | den Elzen, Hof et al. (2014)<br><br>Ministry of Environment and Forestry Directorate General of Climate Change (2021)<br><br>Climate Action Tracker (2023) |
| Nigeria | Reduce emissions by 20% compared to baseline projections, by 2030 | den Elzen, Dafnomilis et al. (2024)<br><br>Climate Action Tracker (2023) |

[2] The updated NDC for 2035 has not yet been incorporated into our assessment

| Country | NDC<br>Emissions reduction target | Source |
|---|---|---|
| | Reduce emissions by 47% compared to baseline projections, by 2030 | |
| Senegal | Reduce emissions by 7% compared to baseline projections by 2030<br><br>Reduce emissions by 30% compared to baseline projections by 2030 | den Elzen, Dafnomilis et al. (2024)<br><br>Climate Action Tracker (2023) |
| South Africa | Limit emissions between 398-510 MtCO2e including LULUCF by 2025<br><br>Limit emissions between 350-420 $MtCO_2e$ including LULUCF by 2030 | den Elzen, Dafnomilis et al. (2024)<br><br>South Africa (2022)<br><br>Climate Action Tracker (2023) |

## 3.3 Current state of climate finance

According to the latest United Nations Framework Convention on Climate Change (UNFCCC) analyses, a total of USD 5 – 6.9 trillion is needed between 2021 and 2030 in order to comply with the NDCs of 98 developing country parties, with annual cost estimates varying in the range of USD 455 – 584 billion per year (UNFCCC 2024c). These amounts do not consider the investments needed for mitigation actions in developed countries and adaptation expenses, classified under the loss and damage fund. Total global flows (public/private/domestic/international) as of 2020 have reached USD 640 billion, with half of it being invested in Asia and the Pacific. Bhattacharya, Songwe et al. (2024) assess the current finance gaps reported by UNFCCC as an underestimation of total costs required to achieve the NDCs of LMICs by 2030.The authors estimate that USD 2.4 trillion is needed annually by 2030 to finance the NDC efforts of LMICs excluding China, which is four times the UNFCC estimate. For 2035 they indicate a further increase to USD 3.5 trillion annually to maintain the ambition.

According to these estimations, total global annual investment required until 2030 is USD 6.5 trillion, of which USD 2.6 trillion are for advanced economies, USD 1.4 trillion for China, and USD 2.4 trillion in other LMICs (Bhattacharya, Songwe et al. 2024). The total financial requirement potentially increases to USD 8 trillion per year by 2035 and its distribution will shift increasingly towards the LMICs to keep ambitions in line with the Paris Agreement. This investment does not consider finance required for adaptation and resilience. The authors further stress that while current investment flows target larger economies such as India or Brazil, several smaller but high-potential LMICs need to be considered more seriously. Examples include the Middle East and Sub-Saharan Africa; in the latter, especially, there continues to be a significant mismatch between clean energy investment and renewable energy potential.

At the COP15 in 2009, developed countries committed to a total finance target of USD 100 billion annually by 2020 for climate action in developing countries (OECD 2024). This goal was reached in 2022 where USD 115.9 billion in climate finance was mobilised (OECD 2024). Public finance made up the largest share (80%) and mitigation-targeted finance continued to dominate adaptation finance. At COP29, parties agreed to triple this target to USD 300 billion annually by 2035 (UNFCCC 2024a). These volumes are defined as finance provided or mobilised by bilateral or multilateral public climate finance. However, parties also recognised the importance of other institutional and private finance and further agreed to scale up efforts towards leveraging USD 1.3 trillion per year by 2035 to developing countries (UNFCCC 2024a). This makes up only about a third of the estimated flows needed in LMICs annually by 2035, according to the LSE assessment (Bhattacharya, Songwe et al. 2024).

Total volumes mobilised by public and private finance are estimated to reach beyond USD 1.5 trillion in 2023, an increase from the USD 1.3 trillion achieved in 2022 (CPI 2024). Mitigation finance made up by far the largest share (90%) of this flow and was mostly made up of projects in renewable energy, low-carbon transport, buildings and infrastructure investment. A considerable decline in technology costs of clean and renewable-based technologies helped generate these significant investments in energy and transport sectors. Other sectors such as industry, waste, and AFOLU have seen lesser investment flows, though the mitigation potential remains high and its implementation will be crucial in order to reach the global Paris targets (CPI 2024).

Another crucial and highly effective finance type is dual benefits finance. These investments are specifically targeting both mitigation and adaptation outcomes, and are therefore likely to benefit from much higher cost-effectiveness. According to the methodology of dual benefits finance used by CPI (2024), these investments grew by 59% between 2018 and 2022, compared to 20% growth in mitigation and adaptation finance. The AFOLU sector, with effective measures such as climate-smart-agriculture and nature-based solutions (NBS), is seen as a key target for these dual benefits.

China is a major player in climate finance as it accounted for 65% of all climate finance flows between 2018 and 2022 in LMICs (CPI 2024). In contrast, the 45 poorest LMICs received just 5% of climate finance during this period. Climate finance flows to LMICs (excluding least developed countries, or LDCs) increased from USD 308 billion in 2018 to USD 823 billion in 2022, of which China accounted for 69%. This can be explained by exceptionally low technology costs, supported by industrial government policies and economies of scale. China's share in global climate finance reached 42% in 2022, up from 27% in 2018.

Given the global economic downturn in 2020 and beyond, countries in Sub-Saharan Africa and Latin America experienced the hardest declines in climate finance. The East Asia and Pacific region did comparatively well due to the efforts of China, and so did other countries like Vietnam with its significant developments in solar. Towards 2022, upward trends in climate finance in countries like South Africa and Pakistan are evident. In 2022, Latin America & the Caribbean, as well as South Asia, make up half of total climate finance to LMICs (excluding China and LDCs) (CPI 2024). Remarkably, China and the East Asia and Pacific region rely nearly exclusively on domestic climate finance flows, thus having little financial dependencies to foreign investors. In Latin America, Brazil increased the share of domestic financing (especially solar investment) to 51% in 2022. Similar developments happened in East Asia that reached 60% in domestic climate finance in 2022.

Despite the growing financial flows, the goal to reach climate neutrality by 2050 requires a change in the level and allocation of investments worldwide. While the investment in established and cost-effective technologies, such as renewable energy and energy efficiency, is expanding, there is also a need to invest in new technologies that are still at the early stage of development, such as Carbon Capture, Utilisation and Storage (CCUS) and green hydrogen. The average annual investment needed to achieve the net-zero target globally is estimated to range between 3.4 trillion US dollars and 8.1 trillion US dollars (Yilmaz, Alswaina et al. 2023) (see Box 3.1 below for the definition of net-zero).

**Box 3.1: What is net-zero?**
Net-zero generally refers to achieving a balance between the amount of greenhouse gases emitted into the atmosphere and the amount removed, effectively resulting in no net increase in atmospheric greenhouse gas concentrations (Fankhauser, Smith et al. 2021). Since achieving absolute zero in all sectors within the timeframe needed is very challenging, net-zero highlights the need for both reduction of emissions from human activities to as close to zero as possible and offsetting any remaining emissions through natural or technological means. This can include initiatives such as reforestation, carbon capture and storage, and investing in renewable energy sources. The pursuit of net-zero is seen as essential to limiting global warming and mitigating the adverse effects of climate change, with many countries and organisations setting ambitious targets to reach this balance by mid-century.

Alongside the identification of these considerable gaps in climate finance, methodological issues persist in measuring and comparing climate finance data. There is no commonly agreed definition of climate finance, such as which countries and what types of finance (e.g. project finance, subsidies) are included, and if and how mitigation and adaptation finance is accounted for (Climate Policy Initiative 2022). This lack of common definition leads to variations in the rules of measurement and transparency protocols of climate finance. Hence, any estimation of climate finance gaps and progress towards climate targets (across countries) needs to be treated with caution (Suroso, Setiawan et al. 2022).

### *Brazil*
According to a recent study by World Economic Forum, Brazil requires an estimated cumulative amount of USD 200 billion to reach its 2030 NDC target of reducing GHG emissions by 48.4% by 2025 and by 53.1% by 2030 compared to 2005 levels (World Economic Forum 2023a). The agriculture and livestock as well as the power sector are expected to take up the major shares in terms of investment (33% and 30%, respectively). In addition, the development of green hydrogen and biofuels will further drive this investment demand.

Between 2020 and 2023, there has been a close to doubling of climate finance into the land use sectors in Brazil. Financial flows considered here are those into agriculture (primary and secondary sectors), forestry, and monitoring and risk management of extreme events. This confirms the great potential Brazil holds in land-based mitigation: research points to potential 60% reduction efforts towards net-zero due to nature-based solutions (NBS) (Soterroni, Imperio et al. 2023). Especially the halting of illegal deforestation or restoration of degraded areas are the most crucial measures for Brazil on its pathway towards its long-term net-zero target.

### *Indonesia*
Indonesia is one of the leading countries in terms of mobilising domestic climate finance over the past few years (CPI 2024). Total domestic finance pledged for climate action until 2030 amounted to USD 18.06 million, while international support until 2021 was USD 26.78 million (UCLG ASPAC 2024). However, the estimated mitigation costs in 2030 alone are projected to reach USD 39.554 million, while total climate action finance needs in 2030, covering both mitigation and adaptation, range between USD 27.73 million and USD 102.43 million. Through its latest Biennial Update Reporting (BUR) in 2021, the Indonesian government estimated the necessary finance requirements for the implementation of mitigation action between 2018 and 2030 at USD 285 billion (Indonesia 2022). At the same time, it was also acknowledged that methodological issues persist in the

estimation of the country's finance needs. Overall it seems that, in the near future, Indonesia is only able to address a minimum of its climate finance needs and requires scaling up, both domestically and internationally.

### *Nigeria*

While the exposure to climate change and associated risks in Nigeria is extremely prevalent, the country also needs to sustain prospective growth and development pathways along with industrialisation and urbanisation strategies (Stout, Gupta et al. 2022). Between 2019 and 2020, USD 1.9 billion was invested in climate finance and USD 17.7 billion is needed annually between 2021 and 2030. Adaptation-related finance is estimated at USD 663 million annually, which seems conservative given the high vulnerability of the country to climate change. The total volumes of adaptation and mitigation finance is 1.1 billion USD annually. The country's updated NDC document mentions investment needs between 2021 and 2030 of about USD 177 billion, with the majority targeting the electricity sector (The Federal Government of Nigeria 2021b).

### *Senegal*

Senegal's first submitted NDC mentions a total finance requirement of USD 13 billion between 2020 and 2030, 70% of which was allocated to mitigation needs in the power, waste and transport sector (Government of Senegal 2020). According to the Country Climate and Development Report (CCDR) of the World Bank (2024a), investment needs in climate action in Senegal amount to USD 8.2 billion between 2025 – 2030. Key investment areas are mostly in water security, urban transport, and the energy system transition. Moreover, adaptation-related investments could focus on more resilient food and environmental systems through climate-smart practices as well as improvements in disaster risk management. Most relevant strategies in its energy transition will be realising the country's extensive renewable energy potential while also relying on domestic gas reserves to quickly move away from high-emitting oil and heavy fuel oil (HFO). While this strategy would prove most cost-effective for Senegal, it would also allow to reach its NDC targets. The CCDR analysis further highlights the importance of securing low-cost power generation and energy accessibility throughout the transition to new energy infrastructure and a new supply chain (World Bank 2024a).

### *South Africa*

Annual climate finance flows in South Africa between 2019 and 2021 were around R 131 billion (around USD 7.3 billion) per year. Estimates suggest that around triple the amount is needed annually to meet South Africa's net-zero goal by 2050 and even five times the amount is needed to reach its 2030 NDC target (de Aragão Fernandes, Gwebu et al. 2023). The bulk of climate finance was mobilised domestically (91%) while only 9% was generated from international sources. As already stipulated in South Africa's NDC priorities until 2030, target sectors of these finance demands will be transport and energy, the latter making up close to two-third of the NDC finance requirement. South Africa's updated NDC further mentions an annual USD 8 billion needed until 2030 and to be spread across adaptation and mitigation action (The Government of South Africa 2021) which falls way below the estimation by de Aragão Fernandes, Gwebu et al. (2023). According to the methodology adopted by de Aragão Fernandes (2023), climate finance flows to South Africa doubled between 2017/18 and 2019/21. Western Europe appears as the largest source of climate finance to the country (57%), followed by East Asia and the Pacific. However, private sector actors do dominate the finance flows.

## 3.4 Economic impacts of climate damages: Risks, losses, and mitigation strategies

Alongside required investment volumes for climate change mitigation and adaptation purposes, the continuation of global warming on a current trajectory of above 1.5 °C already induces significant climate damages and, with that, substantial (non-)economic losses (IPCC 2022). The Global Risks Report (World Economic Forum 2023b) ranks failure to mitigate climate change as one of the most severe threats for the coming decade. Direct economic losses due to extreme weather, climate, and water-related events, without even accounting for loss of life, healthcare-related costs, or damages to ecosystem services, have increased seven-fold from the 1970s to the 2010s (World Meteorological Organization (WMO) 2021). On average, USD 383 million per day of economic losses was reported between 2000 and 2019. Reported economic losses in Asia due to torrential rains, landslides, hailstorms and typhoons, and other climate impacts, amounted to USD 465 billion in the decade from 2010 to 2019. Economic damages from weather-related disasters in North America, Central America, and the Caribbean amounted to over USD 72 billion a year on average in damages between 2010 and 2019. Similarly, these events have caused a reported more than USD 86 billion in damages in Europe between 2010 and 2019. Over 500 reported climate-related disasters in Africa caused direct economic damage of USD 12.5 billion between 12010 and 2019. South America reported direct economic losses of USD 29.3 billion in the same decade.

The IPCC special report on 1.5 °C global warming (IPCC 2018) broadens the implications by presenting that each half degree beyond 1°C of warming amplifies the magnitude of risks and impacts across sectors and regions (Mechler, Singh et al. 2020). It also stresses that poorer and vulnerable groups will be affected relatively more by climate impacts. Moreover, the report attempts to define Loss and Damage (L&D) as adverse impacts and risks induced from both sudden and more continuous climate events. Yet, its differentiation from adaptation-related policy and also whether both current, tangible or future risks should be considered, is still under discussion (Mechler, Singh et al. 2020). A clearer definition exists with respect to the limits of adaptation and what therefore counts as risks and impacts that are certainly unavoidable (hard limits) and those where the lack of current technological or socio-economic solutions does not allow adaptation for now but potentially later.

These discussions have been firstly institutionalised through the Warsaw International Mechanism on Loss and Damage (WIM) and further in Article 7 of the Paris Agreement which recognises the importance of targeting and reducing loss and damages beyond these limits to adaptation (Mechler and Deubelli 2021). With that, also the finance for L&D became an increasingly relevant matter in negotiations and was driven by the broad differentiation between avoidable and unavoidable damages. At COP 28, the first L&D fund was agreed with initial pledges of USD 700 million while the actual needs for unavoidable (committed) damages remain yet under discussion. A lot of these estimates rely on the proven relation between temperature variation and economic development that help determining economic impacts of climate change per location with the help of the so-called damage functions (Tavoni, Andreoni et al. 2024). For 2025 alone, the authors find a median cost of USD 515 billion globally, of which 63% (USD 327 billion) falls on lower-middle income countries. However, in relation to their income levels, low-income countries in Africa are affected most by climate damages. Based on these insights they determine an annual L&D funding requirement of around USD 395 billion. Under various responsibility schemes they show that funding will flow from high-income to lower income countries, while the exact allocation and sufficient amounts (USD 395 billion against a committed USD 700 million) will remain a policy discussion.

Another recent multi-model study indicates that following a 3 °C pathway (RCP 6 scenario), will result in GDP loss of about 10-12% in 2100. In contrast it reduces to about 3% under a well-below 2 °C scenario (RCP 2.6 scenario) (van der Wijst, Bosello et al. 2023). In both pathways the regional damages will be highest for Africa and Asia while the relative impact exacerbates substantially under the 3 °C scenario for these regions. Further comparing the avoided damages (economic benefits of mitigation) to the incurred mitigation costs (at a discount rate of 1.5%), the benefits are almost twice the total discounted costs. This is in line with various studies that show that, globally, avoided climate impacts and damages substantially outweigh the costs of climate mitigation policy (van der Wijst, Bosello et al. 2023).

Moreover, unmitigated climate change not only induces direct damages and losses, but also affects the general investment incentive in economies. It leads to a reduction in available capital and diminishes investment prospects due to lower anticipated returns (Willner, Glanemann et al. 2021). The authors found that the optimal investment path under unmitigated climate change results in a decrease in cumulative investment of 22% by 2100 or USD 104 trillion (compared to a global economy without climate change). These losses are composed of direct damages from climate change (60%), reduced economic growth due to these damages (21%), and a further disincentive to invest given lower returns that exacerbate the economic downturn (19%). Assuming an optimal climate policy and related investment for mitigation of USD 8 trillion, total income losses reduce to USD 35 trillion with only 1% being due to the reduced investment incentive. Direct climate damages with mitigation investment amount to USD 15 trillion, as opposed to USD 63 trillion when no mitigation is happening. This strengthens the economic incentive for mitigation by looking beyond its direct costs and benefits.

# 4 Model outputs and analysis

This chapter discusses the main model outputs for emissions and policy costs under various scenarios at the global level and for the focus regions. The first section of the chapter presents the projected emissions and emission differences between the regional policy scenarios, as well as between the regional policy scenarios and the global cost-effective pathways to demonstrate the ambition gaps. The second section presents the varying roles that sectors play in emissions reduction; in other words, climate change mitigation. The last section discusses the policy costs under various scenarios and the financing gap between meeting the regional policy goals and cost-effective scenarios that aim to meet agreed global temperature targets.

## 4.1 Annual GHG emission trends under various scenarios

### 4.1.1 Global implementation and ambition gaps

Article 2.1 of the Paris Agreement seeks to limit the global average temperature increase to well below 2 °C relative to pre-industrial levels and to pursue efforts to limit this increase to 1.5 °C. The level of global warming is largely determined by the cumulative concentration of emissions in the atmosphere. Hence, the higher the emissions in the first part of the century, the more the need for negative emissions later. The remaining emission budget for a 50% chance of keeping the increase of global warming to a maximum of 1.5 °C above pre-industrial levels (with a 50% probability) is estimated at 250 Gt $CO_2$ at the start of 2023 (Forster, Smith et al. 2023). For the 2 °C target, the remaining emission budget is 1150 Gt $CO_2$. The fair share scenarios allocate higher emission budgets to most low- and middle-income countries, such as Brazil, India, and Sub-Saharan Africa, compared to the cost-effective scenarios (Dekker, Hof et al. 2025). Achieving the Paris goal requires a rapid and significant decline in emissions from all sectors, as well as the enhancement of GHG sinks.

There is also a substantial gap in projected emissions in all regions between the regional policy scenarios and the cost-effective pathways in 2050 as shown in Figure 6. In most regions, emissions in the Extended Current Policy scenario (Ext_CurPol) are far higher than what is submitted under the NDCs, or projected under the cost-effective pathways to limit global temperature increase to well below 2 °C or 1.5 °C above pre-industrial levels. In general, all regions need to do more to align the current policies and NDCs with the Paris Agreement. Both our regional policy scenarios projections, the Ext_CurPol and the Ext_NDC, show that the global emissions remain higher than the well-below 2 °C and 1.5 °C pathways in 2050.


**Figure 6**
Projected regional emissions in 2050 under various scenarios

The global emissions in the Ext_CurPol scenario are projected to reach ~51 Gt $CO_2e$ in 2050 (an average decrease of 0.1% between 2020 and 2050) and leads to a temperature increase of 3 °C above pre-industrial level by 2100, by far exceeding agreed climate goals. The global emissions in the Ext_NDC scenario are projected to reach ~43 Gt $CO_2e$ (an average annual decline of 0.6% between 2020 and 2050), better performance relative to the Ext_CurPol scenario, but still could lead to a temperature increase of more than 2.2 °C by the end of the century. The global emission does not peak until the end of the century in the Ext_CurPol scenario, while in the Ext_NDC scenario, global emissions peak as early as between 2025 and 2030.

Under the Ext_CurPol scenario, there is a substantial increase in emissions between 2020 and 2050 ranging between 65% and 180% in Brazil, North Africa, Sub-Saharan Africa, most of central and south America, India, and other parts of South Asia. Global emissions under this scenario follow a path of steady increase before starting to decline after 2035. Emissions in China under Ext_CurPol scenario peak around 2030, declining steadily with emissions remaining nearly 40% less in 2050 relative to 2020 but remain considerably higher than the cost-effective scenarios. In India and in the sub-regions within Sub-Saharan Africa, we see a one-and-a-half to three-fold increase in emissions in 2050 relative to 2020. Fossil fuels continue to play a major role in the global primary energy mix with coal, oil, and natural gas accounting for nearly 70 – 80% in 2030 and 2050 (see Figure 8). Especially coal, accounting for nearly a third of the primary energy mix, is the main driver of emissions in the Ext_CurPol scenario.

In the 1.5 °C scenario (CostEff_15D), we see a global GHG emissions decline of about 20% by 2030 (in just five years) and nearly 80% by 2050 relative to 2025 projected emissions, which is in 25 years. Some regions will have to considerably reduce their emissions as early as 2030. Emissions in regions like Brazil, Russia, Japan and Korea, and Western Europe already decline by 25%-30% in 2030 relative to 2020, while emissions in low- and middle-income regions, such as Eastern and Western Africa and large parts of Central America, have not yet peaked by that time. The well-below 2 °C scenario (CostEff_20D) shows a similar emissions trend as the 1.5 °C scenario but with fewer reductions. In the CostEff_20D scenario, global emissions decline by 5% in 2030 and by 60% in 2050 relative to 2020. Emissions already start to decline in 2030 in most parts of the world except for Eastern, Western, and Southern Africa, South Asia (including India), parts of Central America, parts of Oceania, and Türkiye. The global emission gap by 2050 between the regional policy scenarios and the 2 °C target is projected to be 24 – 31 Gt $CO_2$e and it is 33 – 40 Gt $CO_2$e between the regional policy scenarios and the 1.5 °C target, which shows the ambition gap.

The NDCs show progress in several parts of the world, but more decisive action needs to be taken to keep the global temperature increase to well-below 2 °C above pre-industrial levels. The global emissions in the Extended NDC scenario are nearly 15% below the projected emissions in the Ext_CurPol scenario by 2050 (an emission gap of nearly 7 Gt $CO_2$e). However, the Extended NDC pathway itself remains considerably higher than the emission paths projected to keep global temperature increase to well-below 2 °C or to 1.5 °C above pre-industrial levels. The emission reduction in NDCs relative to Ext_CurPol is achieved through reducing fossil fuels, especially coal that was cut by half, from the primary energy mix. Non-biomass renewables grow two-fold in 2030 under Ext_CurPol scenario and triple by 2050 relative to 2020. Similarly, in the Ext_NDC scenario, non-biomass renewables nearly quadruple in 2050 relative to 2020.

The emission gap between Ext_CurPol and Ext_NDC scenarios varies by country and region, but the collective action is not enough to meet the targets of the Paris Agreement. The NDCs scenario shows a change in emissions ranging from 45% increase in Indonesia to a 100% decline in the Korea region relative to Ext_CurPol scenario in 2050. In some regions, such as Canada, the United States, and Western Europe, the emissions in the NDCs scenario fall between the well-below 2 °C and 1.5 °C cost-effective pathways, which shows the relatively high level of ambition. For others, like India, China, Indonesia, and Turkey, on the other hand, the Ext_NDC scenario does not perform better than Ext_CurPol scenario in terms of emission reduction. However, it is clear from the graph in Figure 7 that neither the projected collective reductions from NDCs nor current policies are enough to keep the global temperature increase to below 1.5 °C above pre-industrial levels as agreed in the Paris Agreement.

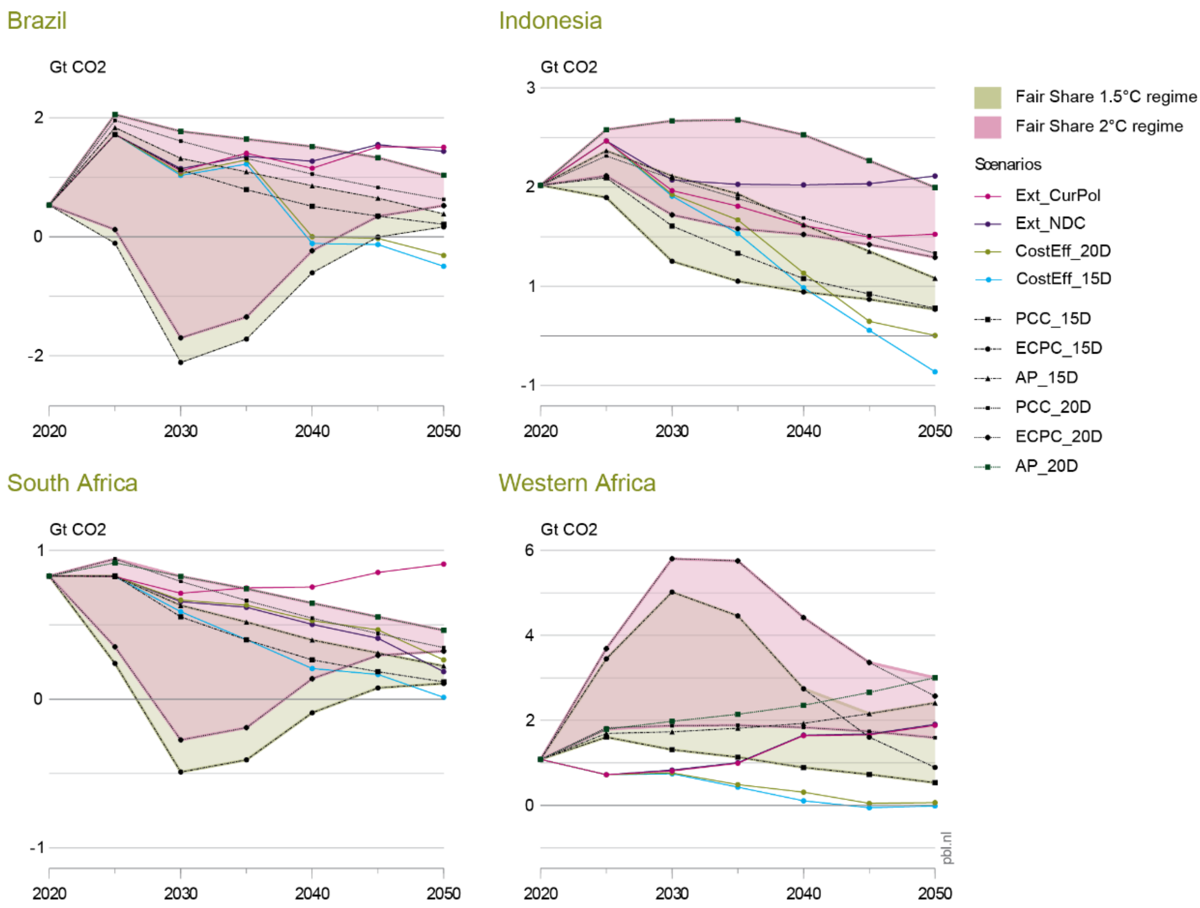


**Figure 7**
Projected regional emission pathways for various scenarios

*Note: The shaded area represents the differentiation in emission budgets under the three effort sharing scenarios in 1.5 °C (rose) and well-below 2 °C (blue) temperature increase. The fair-share scenario lines depicted in the regime are normative benchmarks intended to guide rather than serve as definitive measures of equity. A regional pathway falling within these lines does not automatically indicate that the region is operating fairly or equitably. Conversely, a regional pathway outside the regime suggests that the region is not aligned with fair-share allocations according to all effort-sharing principles. However, these pathways should be evaluated within a broader context, considering various factors that influence fairness beyond mere alignment with the established regime. The expansive area results from the ECPC rule, which seeks to address a region's carbon debt by reducing emissions or compensating for excessive historical emissions early on. This approach can lead to complex and non-linear patterns in the emissions pathways.*

The biggest driver of this emission reduction in the CostEff_20D and the CostEff_15D compared to the Ext_CurPol scenario is the decline of the share of fossil fuels in the primary energy mix by about 40 – 50 percentage points in 2050 relative to 2020, accompanied by a two- to three-fold increase in low-carbon energy sources. In the CostEff_15D scenario, the primary energy supply in 2050 is about 6% lower than in 2020, despite the global population increasing by over 20% and the economy growing by nearly two-and-a-half fold in the same period. In the CostEff_15D scenario, in most high- and higher-middle-income regions, such as large parts of Europe, North America, South America, Japan, and Korea, the primary energy supply declines on average up to 2% a year between 2020 and 2050. However, in low- and low-middle-income regions, such as large parts of Africa, Asia, and South and Central America, the primary energy supply increases by up to 4% a year in the same period. In the CostEff_20D scenario, the primary energy supply increases by 10% in 2050 relative to 2020.

Noticeable is that the decline in fossil fuel shares in total primary and final energy consumption in all regions is similar in most of the scenarios (see Figure 8). In the Ext_CurPol scenario, fossil fuel shares in the global primary energy supply decline to 70% by 2050 from 85% in 2020. The share declines to 45% and 30% in the CostEff_20D and the CostEff_15D scenarios, respectively. A large share of these fossil fuels is deployed in combination with CCS. In the cost-effective scenarios, fossil fuel use declines in absolute terms as early as 2030, while in the current policy scenario, it increases steadily until the end of the century. Renewables, on the other hand, show rapid growth in all scenarios, albeit with a slow start. The message here is that meeting the climate targets would require immediate action and demonstrates the need for countries to strengthen their climate ambitions. It also shows that there is a need for stronger bilateral and multi-lateral collaboration. After all, regions with the most cost-effective mitigation potentials are also the regions that are less developed and mostly have a low technical and economic capacity to implement climate change mitigation measures.

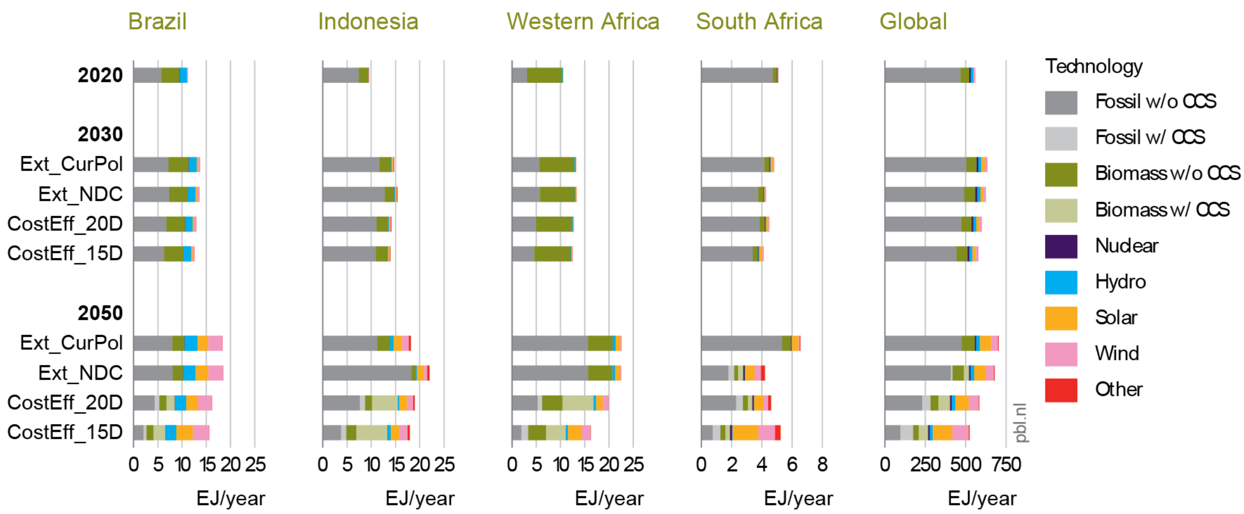


**Figure 8**
Regional primary energy mix

The projected growth of the global final energy demand is moderate (see Figure 9). The total global final energy – the energy that is actually used by the consumer – grows by 20 – 30% from nearly 400 EJ to 490 – 525 EJ between 2020 and 2050 in the policy scenarios. Though most of the growth happens in electricity, fossil fuels remain the dominant source of final energy, providing 45% – 50% of the total in 2050, a decline from 65% in 2020. The share of electricity in 2020 was close to 20%. This is projected to increase to 35 – 40% in 2050, which demonstrates the growing role that electrification plays in decarbonisation and driving energy efficiency. In absolute terms, electricity demand grows more than two-fold between 2020 and 2050, growing from 84 EJ to 183 – 188 EJ, which is particularly driven by the growing demand in transport and industry. For cost-effective scenarios, final energy demand increases by 10% in the 2 °C scenario, while declining by 6% in the

1.5 °C scenario in 2050 relative to 2020. The share of fossil fuels in these scenarios decreases by 20 – 35 %-points in 2050 relative to 2020. Electricity accounts for 40 – 55% of the final energy demand in 2050.

The decline in final energy demand in the CostEff_15D scenario is driven by the efficiency gains from electrification of various sectors. The share of electricity in the final energy mix in the period 2020 to 2050 increases by more than 30 percentage points and the share of fossil fuel declines by nearly 35 percentage points. This trend is similar as in the primary energy supply, where it declines by an annual average rate of up to 1.5% between 2020 and 2050 in high- and higher-middle-income regions but increases by up to 3.5% annual average rate in low- and lower-middle-income regions. This can be explained by the fact that, on average, population increases rapidly in low- and middle-income countries, and the economic is expected to grow strongly.

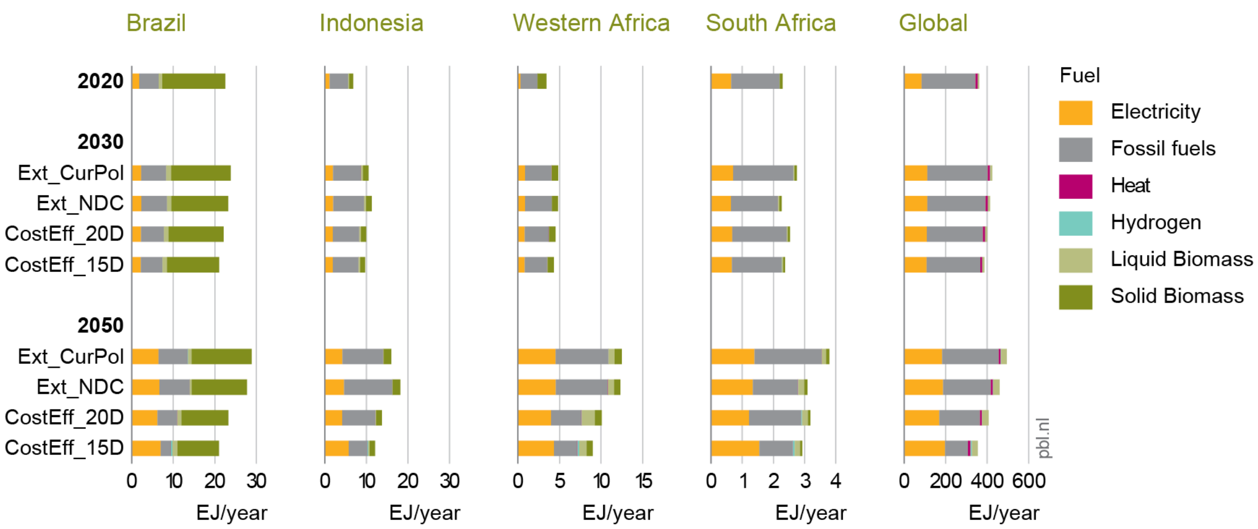


**Figure 9**
Regional final energy mix

## 4.1.2 Brazil

Total GHG emissions in Brazil in the Ext_CurPol scenario are projected to decline on an average rate of 0.6% a year between now and 2050, from 2.6 Gt $CO_2$e to 2.3 Gt $CO_2$e. This emissions decline is driven by the increasing share of electricity and biomass in the final energy mix and reduced deforestation. A similar trend is observed in the Extended NDC scenario, where total GHG emissions decline on an average rate of nearly 0.7% a year between 2020 and 2050, falling to 2.2 Gt $CO_2$e. This trend is also guided by the increasing role of electricity and biomass in the final energy mix together with the declining share of fossil fuels and reduced deforestation. $CO_2$ accounts for nearly 80% of the emission reductions, while $CH_4$ account for 14%-17% in 2050 in the policy scenarios.

The unconditional NDC target for Brazil aims at lower emissions to 1.2 Gt $CO_2$e in 2030, which is a 53.1% reduction from 2005 level (den Elzen, Dafnomilis et al. 2024) . Our projection shows that this target will not be achieved, and the emissions will remain 55% higher than the target. The energy transition is a crucial component of Brazil's NDC ambitions; however, there is no fixed timeline for the phasing out of fossil fuels (Climate Action Tracker 2023). Brazil also includes a goal to reach climate neutrality by 2050 (although no further information is given on the sectors and gases covered). However, neither the Ext_CurPol nor the Ext_NDC scenarios project net-zero emissions by the end of the century.

In the CostEff_15D scenario, Brazil's emission is projected to peak before 2050. In fact, this cost-effective projection shows that the GHG emissions decline rapidly after 2030 and are already net negative by 2050. The country reaches net-zero emissions between 2045 and 2050, while none of the policy scenarios reach climate neutrality within the century. Until 2050, in this scenario, Brazil's emission reduction account for nearly 4% of the global reduction in emissions. In the CostEff_20D scenario, where mitigation is aligned with the effort to limit global temperature increase at the end of the century to well-below 2 °C above industrial level, Brazil’s emissions by 2050 are less than 85% of the 2020 emissions. Net-zero is reached between 2055 and 2060.

There is, however, a substantial gap between emissions in the regional policy scenarios and the global cost-effective scenarios in 2050. Emissions in both regional policy scenarios (Ext_CurPol and Ext_NDC) partially align with the fair-share range for the 2 °C target, but exceed the range by 2040 (see Figure 7). Both of these scenarios do not align with the 1.5 °C fair-share allocations. As a result of that, the emissions gap between the regional policy scenarios (Ext_CurPol and Ext_NDC), and the effort to limit global warming to 1.5 °C, reaches nearly 2.3 Gt $CO_2e$ in 2050. The gap between the policy scenarios and the well-below 2 °C target is around 2.0 Gt $CO_2e$.

Under the Ext_CurPol scenario, the final energy demand shows a steady growth of an average of 1.7% between 2020 and 2050, growing from 9 EJ to 15 EJ per year. In the Ext_NDC scenario, the average annual growth in final energy demand is slightly higher, with 1.8% between 2020 and 2050. The growing share of electricity in the final energy demand from 20% in 2020 to over 40% in 2050 enables emission reduction despite the growing demand for energy. As can be seen from the primary energy mix (Figure 8), the growing share of renewables and the integration of CCS in fossil fuels and bioenergy also play a considerable role in reducing emissions in the regional policy scenarios. The primary energy trend is also similar between the Ext_CurPol and Ext_NDC scenarios, where primary energy consumption grows by nearly 65% between 2020 and 2050 in both scenarios, with coal, oil, and gas demand declining considerably.

In the global cost-effective scenarios, rapid electrification and energy efficiency halt the continuing growth of the final energy demand that is observed in the Ext_CurPol scenario. Unabated fossil fuels in the primary energy mix are also replaced by a natural gas and CCS combination, biomass with and without CCS, and non-biomass renewables. Total primary energy supply grows at a slow but constant pace despite driven by the projected population increase and economic growth. The share of fossil fuels in the primary energy supply fall by nearly 10%-points relative to 2020, while the contribution of renewable energy grows by a similar amount.

Hence, rapid electrification and improved efficiency in industry and transport, together with an increasing contribution of biomass, wind, and solar in electricity generation, are the main drivers of the emission mitigation effort. The rapid emissions reduction and the negative emissions in the cost-effective pathways are resulting from AFOLU sequestration, and the use of CCS in combination with fossil fuels and biomass. But these measures need to be strengthened after 2030 to prevent the growing gap between policy pathways and target emission trajectories.

### 4.1.3 Indonesia

Indonesia is the fourth most populous country in the world and the seventh-largest economy. Indonesia is also by far the largest coal exporter in the world (Jakob and Steckel 2022). Under the Ext_CurPol scenario, total emissions in Indonesia are projected to fall on average by 1.4% a year between 2020 and 2050 after peaking in the early 2030s. A substantial proportion of the emissions come from the AFOLU sector, particularly conversion of peatlands into agricultural plantations, as well as the energy sector (World Bank 2021). The reduction in emissions reflects the decline in the use of fossil fuels, especially coal, in the primary energy mix and the growing role of renewables in the energy system (see Figure 8). The Ext_NDC scenario shows less reduction in GHG emissions compared to the Ext_CurPol scenario. The average annual emission decline is around 0.2% between 2020 and 2050, and the share of fossil fuels in the primary energy mix increases from 70% in 2020 to 80% in 2050, while the share of renewables declines from 30% to 20%.

The conditional NDC emission reduction targets in Indonesia, as submitted in the enhanced NDC in 2023, is 43% below the business-as-usual scenario in 2030. Climate Action Tracker (2023) translates this to 1710 Mt $CO_2$e, excluding LULUCF emissions. As can be seen in the Figure 7, emissions in the Ext_NDC pathway are higher than in the Ext_CurPol scenario. Indonesia is also exploring pathways that could lead to net-zero by 2060 or sooner. However, emissions in both regional policy scenarios do not reach net-zero in this century.

Indonesia shows a similar emission trend as Brazil in the CostEff_15D scenario. The total emissions in this scenario decrease by over a 100% by 2050 relative to 2020, peaks before 2030, and reaches climate neutrality before 2050. This would entail an average annual emission reduction of over 5% between 2020 and 2050. Indonesia contributes to 7% of the global emissions reduction in 2050 in the 1.5 °C scenario. In the CostEff_20D scenario, total emissions reduce by nearly 90% in 2050 relative to 2020. Net-zero is reached between 2050 and 2060 with an average annual emission reduction of over 6% until 2050. There is a considerable decline in emissions in the policy scenarios relative to 2015 emissions amounting to 500 Mt $CO_2$e and 150 Mt $CO_2$e in the Ext_CurPol and Ext_NDC scenarios, respectively, in 2050.

The policy scenarios in Indonesia are far from the cost-effective scenarios in terms of emission reduction. The emission gap between SSP2_1.5D and the regional policy scenarios in 2050 is 1.5 – 2.1 Gt $CO_2$e, equivalent to the current Brazil emissions. The policy scenarios align with the 2 °C fair-share allocation throughout the first half of the century but remain slightly above the 1. 5 °C fair-share emission regime. Therefore, compatibility with the 1.5 °C fair-share scenario requires a strengthening of current climate policies and the unconditional NDC targets.

The final energy consumption in the policy scenarios is projected to grow at an average annual rate of 1.7% between 2020 and 2050. In the same period, the share of fossil fuels in the final energy mix remains constant, close to 65%. At the same time, the share of electricity grows from 15% in 2020 to 30% in 2050, contributing to emissions mitigation despite the continued consumption of fossil fuels. Primary energy consumption shows a similar path increasing at an average annual rate of 2.2 – 2.8% between 2020 and 2050, thereby reaching 18 – 22 EJ. Contribution of fossil fuels to the primary energy mix decreases from 80% to 60% between 2020 and 2050 in the Ext_CurPol scenario. The share of clean energy in the primary energy mix increases from 21% in 2020 to 40% in 2050.

The emission reduction pathways are dependent on the continuation of progress made in Indonesia in reducing deforestation together with improved efficiency and electrification of the industry and transport sectors. Important measures to align climate change mitigation with the global commitment to keep temperature increase to 1.5 °C above pre-industrial levels could include extension of land-based policies that will cover the permanent banning of primary forest and peatlands conversion, extending moratorium policy to include secondary forest, enforcing better peatlands ecosystem management, and fires mitigation policies (Wijaya, Samadhi et al. 2019). Rapidly shifting away from fossil fuels in electricity production and transport also contribute considerably to the mitigation effort.

### 4.1.4 South Africa

Currently, South Africa has the highest emission rates in Sub-Saharan Africa. Despite the projected economic growth, total emissions in South Africa are projected to remain stable for the next couple of decades under the Ext_CurPol scenario. The Ext_NDC scenario projects a considerable decline in emissions with over 4% annual reduction between 2020 and 2050. This means that the emissions in the Ext_NDC scenario are 70% lower than the projection under the Extended Current Policies scenario, equal to 375 Mt $CO_2$. Emissions in the Ext_CurPol scenario remain far from the global cost-effective scenarios, as well as the fair-share emission budgets under the 1.5 °C and well-below 2 °C allocations.

Meeting the global climate target requires countries to take ambitious steps to drastically reduce their GHG emissions and transition to a low-carbon economy. South Africa's emissions are projected to peak before 2030 and, in the CostEff_15D scenario, continue to decline until the end of the century. The total emissions are 30% and 90% lower relative to 2020 by 2030 and 2050, respectively. The CostEff_20D scenario gives a bit more room for emissions. The total GHG emissions are 20% lower in 2030 relative to 2020, and 60% lower by 2050 relative to 2020. The 1.5 °C scenario reaches net-zero before 2070, while the well-below 2 °C does not reach net-zero until the late 2080s.

The emission gap between the current policies scenario (Ext_CurPol) and the 1.5 °C scenario is 465 Mt $CO_2$e in 2050 (equivalent to 90% of the country's 2023 GHG emissions). The CostEff_15D scenario aligns well with the fair-share range for the 1.5 °C target. The gap between the Ext_CurPol and the 2 °C target (CostEff_20D) is projected to be 335 Mt $CO_2$e in 2050. The NDC scenario (Ext_NDC) actually performs better than the 2 °C scenario in terms of emission reductions. In fact, projected emissions under the Extended NDC scenario by 2050 are 20% less than the CostEff_20D projected emissions. The Ext_NDC also falls well with in the 1.5 °C fair-share emissions range for South Africa towards mid-century. This shows that South Africa's conditional NDCs are ambitious enough to contribute to the global 1.5 °C target and remain within the fair-share emissions range.

Despite the high economic growth projected under the SSP2 scenario, the primary energy demand growth in the Ext_CurPol scenario is modest, increasing from 5 EJ to 6.5 EJ between 2020 and 2050, an annual average growth of 0.85%. South Africa's primary energy mix is dominated by coal in the Ext_CurPol scenario; it accounts for 60% in 2050, a decrease from 70% in 2020 amid the efforts to diversify energy sources. Fossil fuels contribute to 80% of the total primary energy supply, slightly lower than the share in 2020. The Ext_NDC scenario shows an even better improvement in energy efficiency, with primary energy supply declining on an annual average rate of 0.6% between 2020 and 2050 to reach 4.2 EJ. In the scenario, the share of coal, the fuel that accounted for 85% of the $CO_2$ emission from fuel combustion in 2022, in the total primary energy plummets to 2%. Nearly

70% of the remaining coal and more than half of the total fossil fuel in the primary energy supply is used in combination with CCS.

The final energy mix also shows a similar trend where the use of fossil fuels declines, and the share of low-emission fuels increases over the years, with a strong contrast between the two regional policy scenarios. The share of electricity grows from 25% in 2020 to 36 – 50% in 2050 in the regional policy scenarios. This requires the diversification of electricity production away from coal dependency and expansion of generation capacity to overcome the current energy crisis that led to record-breaking levels of load shedding, seriously impacting the economy (Climate Action Tracker 2023). The share of all fossil fuels remains at 55% in the Ext_CurPol scenario, slightly lower than the share in 2020, and declines to 45% in the Ext_NDC scenario.

South Africa's updated NDC aims to cut emissions in 2030 to 350 – 420 Mt $CO_2$e, including LULUCF emissions. The emissions projection in the Ext_NDC scenario is close to the lower end of this range. Figure 7 also shows that the projected NDC emissions fall well within the country's emission budget in the 1.5 °C fair-share allocation. This means that South Africa's NDC targets are compatible with the targets that aim to limit the global temperature increase to 1.5 °C above pre-industrial levels and align well with the fair-share contribution. South Africa also targets net-zero carbon emissions by 2050 which neither of the policy scenarios achieve.

The emission reduction in 1.5 °C scenario is largely achieved by reducing the use of coal, virtually eliminating all coal use without CCS. In addition, the use of gas increases in combination with CCS, and a rapid increase is visible in shares of nuclear, hydro, solar and onshore wind in the primary energy supply. In the 2 °C scenario, on the other hand, the use of coal also declines but still contributes substantially to the primary energy supply. The use of gas increases slowly both with and without CCS. Renewable energy and nuclear in cumulative generation capacity grow rapidly until 2050. Decommissioning coal powerplants, expanding and fast-tracking renewable energy projects, and investing in energy storage has multiple benefits beyond emissions reduction, including reduction of air pollution and improved reliability of the electricity system.

### 4.1.5 Western Africa (Nigeria and Senegal)

The combined GHG emissions of Nigeria and Senegal in 2022 (with a combined population of more than 240 million) was equivalent to the total emissions of France. In our model, Nigeria and Senegal are modelled as part of the Western Africa region. Western Africa contributed to nearly 2% of the global emissions in 2022, and Nigeria alone accounted for nearly 50% of those emissions and Senegal around 5%. Both regional policy scenarios, the Ext_CurPol and the Ext_NDC, show similar emission pathways. In these scenarios, the total emissions in Western Africa are projected to grow by half by 2050, with an average annual growth of 1.25%. In these scenarios, the regional emissions will keep growing throughout the century. The emission growth is driven by the increasing shares of fossil fuels in the primary energy mix from slightly above 25% in 2020 to around 70% in 2050, driven by rapid increase in the consumption of oil and gas.

In the 1.5 °C cost-effective scenario (CostEff_15D), the total GHG emissions of the region peaks before 2030 and becomes carbon neutral before 2070. In this scenario, the region's emissions are 75% below the 2020 emissions demonstrating the potential of the region to decouple emissions and development. In the CostEff_20D scenario, the total emissions in Western Africa by 2030 are already 20% lower than 2020 and start to decline faster afterwards. The emission gap between the policy scenarios and cost-effective 1.5 °C and 2 °C scenarios is in the range of 2.0 – 2.2 Gt $CO_2$e, roughly equivalent to the current combined emissions of Indonesia and Brazil.

The final energy consumption in the region grows at an average annual rate of 1.5% between 2020 and 2050 in the two policy scenarios. In absolute terms, the final energy consumption in the region grows from 9 EJ in 2020 to close to 15 EJ in 2050. The share of fossil in this period increases from 21% in 2020 to more than 40% in 2050. The share of electricity also grows from 3% to almost 30% between 2020 and 2050 slowing the growth in total emissions. The increase in the use of biomass and natural gas in combination with CCS in primary energy in the global cost-effective scenarios reduces the emission intensity of the overall economy in the region. There is also a rapid growth in the use of renewable energy sources, albeit after a very low start. The role of unabated coal reduces over the years in both the CostEff_15D and CostEff_20D scenarios. The share of electricity in final energy in the region increases from 3% in 2020 to 30 – 40% in 2050. Just like the rest of Africa, given the considerable renewable energy potential on the continent, electricity sourced from renewables is one of the main pillars of the decarbonisation path. The share of natural gas in the final energy mix also grows from 2% in 2020 to 7% in 2050 as demand from industry grows.

Western Africa, having an exceedingly small historical contribution to emissions, has a higher emission budget than several other regions in both 1.5 °C and 2 °C fair-share allocations. Both regional policy scenarios align well with the 1.5 °C fair-share allocation. It should be noted that the wide range of the allocations are the results of the physical or social uncertainties, the global goals and fairness considerations that are inherent to these principles. Having said that, the climate change mitigation potentials of western Africa is enormous and can contribute to the global goal of limiting the temperature increase to well-below 2 °C provided that there is a collaboration in capacity building, access to enhanced financial resources, technology transfer and technical cooperation.

*Nigeria* is the biggest oil producer in Africa (IEA 2023a). In 2022, fossil fuels accounted for 55.5% of the energy supply, 46.2% of final consumption, and 75.5% of the electricity generation (IEA 2023a). Energy-related emissions in Nigeria in 2022 were 100 Mt $CO_2$, accounting for a mere 0.3% of global emissions. The unconditional targets of Nigeria, as submitted in the 2021 update of its NDCs, aim to reduce emissions 20% below the business-as-usual by 2030 (Noah 2024). The conditional targets aim to reduce emission by 47% relative to Business-As-Usual by 2030, which according to Climate Action Tracker (2023) equates to 201-264 Mt $CO_2$e in 2030 (excluding LULUCF). Nigeria estimates total emissions in the Business-As-Usual scenario to reach 453 Mt $CO_2$e in 2030 (The Federal Government of Nigeria 2021b), which is 11% lower than the 2022 emissions (EDGAR 2023). Nigeria also aims to reach net-zero by 2060. The measures for achieving most of this reduction include ending gas flaring, accelerating the deployment of solar PV, improved efficiency of gas generators, improved overall energy efficiency, climate smart agriculture, and reforestation.

Nigeria’s net-zero ambition is not reflected in the regional emission pathway as neither of the policy scenarios lead to a net-zero before the last decade of the century. The country is a crude oil producer and the income from fossil fuel export represents a significant financial flow to the government. The high carbon intensity of the country's economy and the dependence of the government on income from fossil fuels amplify the challenge of decarbonising Nigeria’s economy. At the same time, the country is experiencing the impacts of climate change through desertification in the north, floods in the centre, pollution and erosion on the coast, and the associated socio-economic consequences (The Federal Government of Nigeria 2021c).

Nigeria's climate ambitions are supported by the National Climate Change Policy (Federal Ministry of Environment 2021b) approved in 2021 and the Nigeria Climate Change Act (The Federal Government of Nigeria 2021a) signed into law in 2021. The Energy Transition Plan that outlines a substantial emission reduction in the power, cooking, oil and gas, transportation, and industry sectors was also unveiled in 2022 (The Federal Government of Nigeria 2021c). The long-term objectives include reducing the carbon intensity of the economy, improve the overall energy efficiency, expand electricity generation capacity, improve energy security, and tap into the economic opportunities of the global path to decarbonisation (Okoh and Okpanachi 2023).

The decarbonisation pathways depend on improving access to electricity to eliminate the use of diesel generators for power generation and facilitating the transition to modern cooking services. Nigeria has considerable renewable energy potential that could provide green energy not only to the country but to the entire region. Despite this potential, lack of access to affordable and reliable electricity is impeding industrial production and economic development. Most firms rely on on-site diesel generators for electricity or as back-up in case of grid failure (Federal Ministry of Environment 2021a). Given the projected population growth and economic output, emissions from energy use are projected to increase substantially unless rapid improvements are made in improving access and efficiency. On the other hand, the effort-sharing scenario provides a wide range for the Nigerian carbon budget given its low contribution to historical emissions, low stage of economic development, and limited capability to mitigate emissions.

For Western Africa as a whole, the projected regional emissions in the NDC commitments and current policies are well within the 1.5 °C effort-sharing budget range. The regional emission gap between the effort-sharing budget and the cost-effective scenarios indicates that the region can contribute to cutting emissions to meet global temperature targets with enough external support.

With the growing population and economy, total energy supply in *Senegal* grew from 212 PJ in 2011 to 232 PJ in 2022. In 2022, oil and coal accounted for two-thirds of the energy supply, with non-biomass renewables accounting for less than 2%, and biomass providing the rest of the primary energy supply. The electricity mix is dominated by coal and oil that account for 85% of the electricity generation. The $CO_2$ emissions from fuel combustion have grown by three-fold between 2000 and 2022 from 4 Mt $CO_2$ to nearly 12 Mt $CO_2$ (which is less than a one-day emission from fuel combustion of the USA), with oil accounting for over 80% of this emission. Despite this growth, the low level of consumption and access to modern fuels means Senegal accounted for a mere 0.03% of the global energy-related $CO_2$ emissions (IEA 2023a). Total GHG emissions in Senegal has been steadily increasing over the years and reached 30.6 Mt $CO_2e$ in 2022 (EDGAR 2023), which is around 20% of the total emissions of the Netherlands (PBL 2024b). Agriculture, industry, and the power sector account for 40%, 20%, and 11% of these emissions, respectively.

Senegal's NDC states concrete actions for increasing renewables, improving energy efficiency, and clean energy technology deployment. In the NDCs submitted in 2020, Senegal targets reducing GHG emissions by 23% and 29% in 2025 and 2030, respectively, relative to the Business-As-Usual scenario with a strong focus on the energy sector. The unconditional renewable targets have already been met in 2023 (IEA 2023b).

Senegal is already feeling the impact of climate change through rising temperatures, erratic rainfall, weather-related hazards, coastal erosion, and rising sea-levels. Tomalka (2021) projects that, under varying GHG emissions, air temperature over Senegal will increase by an average of 1.7 – 1.8 °C by 2030 and 2.1 – 2.2 °C by 2050 relative to pre-industrial levels.

The new development plan of Senegal, Vision Sénégal 2050 (VS50) (Government of Senegal 2024), aims to triple the country's per capita income by 2050. The country aims to develop all available natural resources, including oil and gas, to drive economic development, make Senegal energy self-sufficient, and create opportunities for the youth. The energy sector is at the heart of the country's strategy for sustainable and economic development and aspiration to become an emerging economy. With an expectation of further acceleration of the exploitation of fossil fuels, emissions from fuel combustions require additional attention.

## 4.2 The role of sectors in emission reduction under various scenarios

Meeting the goal to keep the global temperature rise this century to well below 2 °C above pre-industrial levels as well as pursuing efforts to limit the temperature increase to 1.5 °C, requires global emissions to be cut substantially (United Nations Environment Programme 2022). All sectors – AFOLU, electricity supply, industry, transport, and buildings – will play a role in achieving this goal, but their role varies by scenario and region depending on the structure of the economy. This section explores the role of these sectors in climate change mitigation in the selected regions under the various scenarios.

### 4.2.1 Global sectoral contribution to global emission reduction

Closing the implementation gap between current policies and NDCs, and the ambition gap between NDCs and long-term climate goals, is essential to limiting global warming. Therefore, current policies need to be scaled up to meet current NDC (submitted in 2020) reductions and ambition in NDC pledges needs to be increased to bring the global GHG emissions to levels consistent with the well-below 2 °C and 1.5 °C pathways. To facilitate development, LMICs require climate finance and enhanced human and institutional capacity building support from high-income countries..

Our model projections show that the global ambition gap between the NDCs (Ext_NDC) and 1.5 °C scenario (CostEff_15D) in 2035 amounts to 15 Gt $CO_2e$, while the global implementation gap between the current policies (Ext_CurPol) scenario and the NDC (Ext_NDC) scenario by 2035 is 2 Gt $CO_2e$. The projected implementation gap increases to 7 Gt $CO_2e$ and the ambition gap to 35 Gt $CO_2e$ by 2050 (see Figure 7). Note that most current policies are defined until 2030, and we assume equivalent effort between 2030 and 2050.

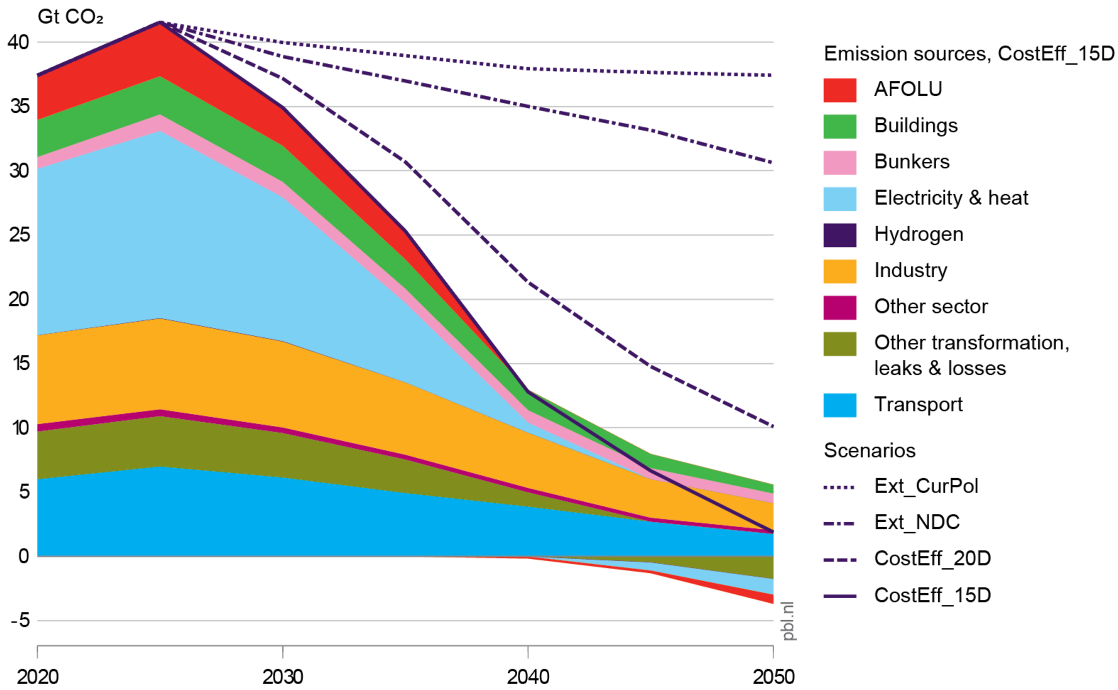


**Figure 10**
Sectoral $CO_2$ emissions in the CostEff_15D scenario and total $CO_2$ emissions in all scenarios

*Note: In the sectoral emission figures below, emissions from electricity, heat, and hydrogen are allocated to the demand sectors.*

Fossil fuel combustion remains the dominant driver of GHG emissions. Figure 10 shows the reduction potentials of the economic sectors in the 1.5 °C scenario (CostEff_15D) and the projected $CO_2$ emission in the current policies (Ext_CurPol), the NDCs (Ext_NDC) and well-below 2 °C (CostEff_20D) scenarios. Despite efforts to cut these emissions, the model projections highlight that $CO_2$ emissions for current policies and NDCs are not consistent with pathways aiming to limit global temperature increase to well-below 2 °C or 1.5 °C to pre-industrial levels.

The energy supply sector is a key contributor to global $CO_2$ emissions and presents a major opportunity for mitigation. In 2020, emissions from energy supply in the regional policy scenarios accounted for approximately 30% of total global $CO_2$ emissions. This percentage is projected to stay at the same level by 2050 in the Ext_CurPol scenario. In the Ext_NDC scenario, it decreases to a slightly lower percentage, resulting in a 25% reduction in absolute value compared to current policies. The primary source $CO_2$ emissions in the energy supply sector originate from electricity production, which account for approximately 70% of the emissions in this sector by 2020. The increase of these emissions by 2050 relative to 2020 is around 5% in the Ext_CurPol scenario but decreases by around 12.5% in the Extended NDC scenario. Through accelerating the deployment of renewable sources, phasing out unabated coal power-plants, and improving efficiency, the power sector has the potential to mitigate around 2 Gt $CO_2$ by 2050 in the Ext_NDC scenario relative to current policies (Ext_CurPol scenario). Although costs for solar and wind are decreasing rapidly, scaling up renewables in developing countries often have higher electricity costs due to limited access to clean energy technologies, and are often locked into fossil fuel generation. Hence, adequate flows of international (concessional) finance are essential to facilitate the transition (World Bank 2023).

Decarbonising the power sector is the cornerstone of cost-effective climate mitigation pathways that aim to keep temperature increase below the Paris temperature goals. Both the well-below 2 °C and 1.5 °C scenarios achieve the bulk of the emission reductions through deep cuts in the power sector (see Figure 10). In this period, the global electricity demand more than doubles in both the CostEff_15D and CostEff_20D scenarios. As a result, the regional electricity supply in the CostEff_15D scenario between 2020 and 2050 varies between a 4% decline in Japan to a more than 2500% growth in Eastern Africa. In these scenarios, the share of renewable primary energy grows from around 15% in 2020 to 30 – 60% in 2050. At the same time, the share of fossil fuels without CCS is declining from 85% to 30 – 70% in the same period. This is particularly the case in China, India, Indonesia, Japan, the Middle East, South Africa, and Southeast Asian regions where there is a rapid increase in electricity demand while electricity generation itself is dominated by fossil fuels. Reducing global emissions from electricity production by 2050 provides time to develop cleaner fuels, such as hydrogen and synthetic options, to enter the mix at a later stage to mitigate emissions in sectors that are difficult to electrify. The transition to cleaner electricity sources has co-benefits like creating decent jobs, improving air quality, and expanding access (Dagnachew, Hof et al. 2021).

Emissions from the energy supply are considered indirect emissions to the energy demand sectors, particularly buildings and transport, whereas for hard to abate industry sectors, multiple avenues can be considered. Electricity, heat, and hydrogen are consumed across all demand sectors (see Figure 11), meaning their emissions are indirectly attributed to end-use sectors –mostly $CO_2$, unless noted otherwise. In 2020, the highest percentage of indirect emissions in the current policies scenario occurred in the buildings sector, while the transport sector had the lowest percentage. Note that for the AFOLU sector, indirect emissions are excluded as they are not explicitly modelled in IMAGE since they are small compared to $CO_2$ from land use and non-$CO_2$ from agriculture.
The AFOLU sector in particular plays an important role in land-intensive economies. Concerning $CO_2$ emissions, only land use and land use change (LULUCF) are crucial in the AFOLU sector and contribute a substantial share of emissions in countries such as Brazil and Indonesia. The global AFOLU sector is responsible for 7% of global $CO_2$ emissions in 2020 but is close to 30-40% in Brazil and Indonesia. Note that there is a discrepancy between global models and national greenhouse gas inventories (see Box 4.1). The global AFOLU $CO_2$ emissions are projected to increase to around 3.5 Gt $CO_2$ by 2050 in the Extended Current Policies and the Extended NDC scenarios, respectively.

**Box 4.1 Methods to estimate land use CO2 emissions**

Estimating $CO_2$ emissions from land use is challenging due to the complex and variable nature of natural processes, as well as the different methods used to account and report for them. Two common reporting standards in modelling studies are accounting methods and bookkeeping methods. Accounting methods based on the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) are primarily used by countries for their annual GHG inventories and assume that emission reductions (negative emissions) due to forest management and $CO_2$ fertilisation effects (increased photosynthesis from higher $CO_2$ levels) are anthropogenic (Grassi, Stehfest et al. 2021, Gidden 2023, Friedlingstein, O'Sullivan et al. 2025). In contrast, bookkeeping methods that are mostly used by integrated assessment models assume these emissions are natural. As a result, accounting methods typically report lower current emissions due to higher land use $CO_2$ sinks. This discrepancy currently amounts to about 5.5 Gt $CO_2$ globally, although this is expected to reverse before 2100 (Gidden 2023).

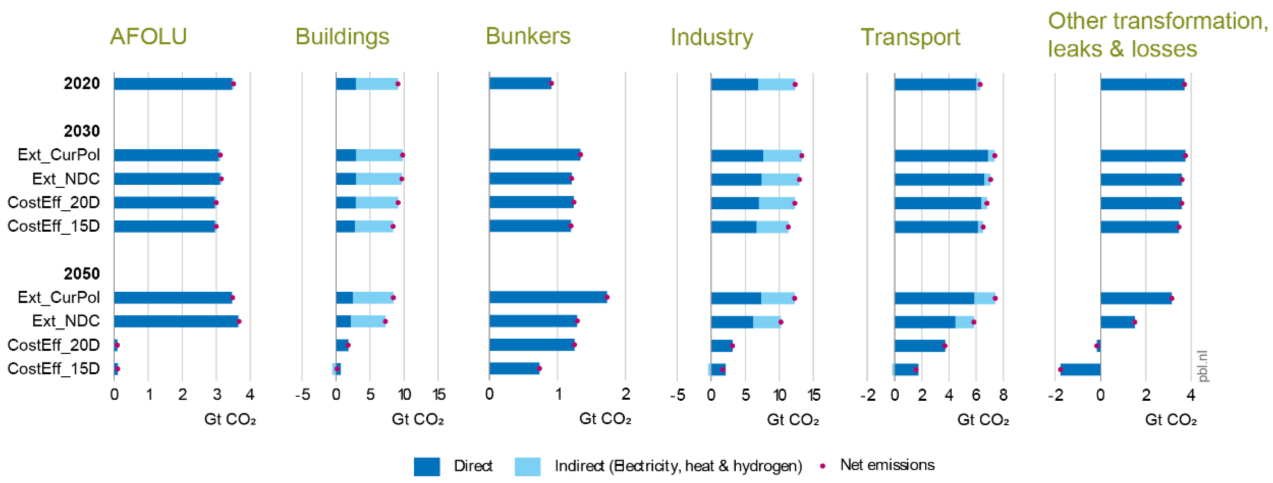


**Figure 11**
Global sectoral $CO_2$ emissions under various scenarios including electricity, heat, and hydrogen

*Note: Emissions from fuel extraction and processing includes biofuel production.*

The AFOLU sector is pivotal for cost-effective global climate mitigation and reaching net-zero targets. The net AFOLU emissions by 2050 approach zero in both the 2 °C and 1.5 °C scenarios, balancing out positive emissions from deforestation and negative emissions for afforestation (planting trees). In the Ext_NDC scenario, the emissions remain around the 2020 levels of 3.5 Gt $CO_2$. In the cost-effective 1.5 °C scenario, the contribution to global AFOLU emissions varies significantly across regions. While China is projected to have a net sink of 400 Mt $CO_2$ by 2050, the South America region (excluding Brazil) is a source of 450 Mt $CO_2$. If effectively implemented, climate change mitigation measures in the AFOLU sector—such as the protection, improved management, and restoration of forests and other ecosystems, soil carbon management, agroforestry, biochar, rice cultivation, and livestock and nutrient management—can reduce emissions considerably and sequester large volumes of carbon. These measures also offer co-benefits, such as improving air quality, enhancing food and water security, and improving the livelihood of rural communities (Dagnachew, Hof et al. 2021). However, inappropriate or misguided design and implementation of measures can have negative implications for food security and livelihoods for the poor in low- and middle-income countries depending on the type of measure and implementation strategy (Nabuurs 2022).

The industry sector is a major source of $CO_2$ emissions, with limited reductions under the Extended Current Policies scenario. Direct and indirect emissions from industry account for 11.5 Gt $CO_2$, which is approximately 30% of global $CO_2$ emissions in 2020. They are projected to remain about the same by 2050 in the Ext_CurPol and decrease to around 9.5 Gt $CO_2$ in the Ext_NDC scenario. The final energy demand for the sector is projected to increase from 120 EJ in 2020 to around 150 EJ by 2050 in the policy scenarios, which is an average annual growth of 0.7 – 0.8% between 2020 and 2050. This is driven by population increase, economic development, and income growth. The share of electricity in the industry final energy mix grows from 30% in 2020 to close to around 45% in 2050 in the policy scenarios. At the same time, fossil fuels (with and without CCS) decrease from 20% by 2020 to around 12% by 2050. The share of hydrogen remains negligible in both policy scenarios (see Figure 12). The slow penetration of alternative low-carbon fuels in sectors that are hard to electrify has limited the ability of these sectors to reduce emissions more drastically in the Ext_CurPol and the Ext_NDC scenarios. In addition, the integration of hydrogen in the energy system depends on the availability of sufficient renewable capacity, space for infrastructure development, and the promotion of innovation through R&D and government policy.

In the industry sector, strong climate ambition is needed to achieve the Paris goals. In the CostEff_20D, industrial emissions reduce to 3 Gt $CO_2$ in 2050 and then further to 1.5 Gt $CO_2$ in the CostEff_15D scenario, benefiting from deep mitigation in the electricity sector and increased biofuel production, as well as accelerated energy efficiency. In the 1.5 °C scenario, the share of biofuel in the sectoral fuel mix almost stays at the same level between 6-8% in the period from 2020 to 2050, while the electricity share increases from 30 to 45%, which is only slightly more than in the policy scenarios (see Figure 12). The share of hydrogen in the industry final energy mix reaches 3%, a higher growth relative to the other scenarios. The industry sector has the potential to reduce 7 – 9 Gt $CO_2$ beyond what can be achieved by the NDCs through electrifying industrial processes, integrating green hydrogen into the energy system to decarbonise sectors that are difficult to electrify, accelerating material efficiency and scaling up energy efficiency, and reducing emissions from the oil and gas sectors (United Nations Environment Programme 2022).

The transport sector is another major contributor to global $CO_2$ emissions, with limited progress under current policies. In the Ext_CurPol and Ext_NDC scenarios, global emissions, including indirect emissions, are projected to reach 5.8 – 7.3 Gt $CO_2$ by 2050, representing around 20% of global $CO_2$ emissions. This is 15% higher for Extended Current Policies and 10% lower for Extended NDCs compared to the level in 2020. China, India, the United States, and the Middle East account for more than 50% of the global transport $CO_2$ emission in 2050. Most of the relative increase in transport emissions take place in low- and middle-income countries in Africa and Asia but they start from a lower level; hence the absolute impact on global emission remains small. At the same time, emissions from fuel used for international aviation and maritime transport (bunker emissions) grow between 40 – 90% between 2020 and 2050 even though part of the fossil fuels used in this sector are replaced with biofuel and other sustainable marine fuels. Passenger and freight transport in kilometres is forecast to grow substantially in low- and middle-income countries driven by economic expansion, trade growth, and urbanisation (IEF 2024), while at the same time there is evidence of decoupling transport emission from economic growth (Jaramillo 2022).

Deep decarbonisation of transport is possible in the more ambitious climate scenarios. In the 1.5 °C pathway, the projected (direct and indirect) $CO_2$ emissions in the transport decrease to around 1.5 Gt $CO_2$ by 2050. This is achieved by a major shift in the energy mix: biofuels are projected to account for 15%, electricity for 45%, and hydrogen for 2% (see Figure 11). At the same time, the fossil fuel share is declining from 95% in 2020 to 20% in 2050 (see Figure 12). In the well-below 2 °C scenario, the transport $CO_2$ emission amount to 3.7 Gt $CO_2$ in 2050, which is almost 3 Gt $CO_2$ less than what is achieved by the NDCs. Biofuel, electricity, and hydrogen replace part of the fossil fuels in the sector to meet climate change mitigation objectives. In addition to the strong shift towards low-emission transport modes, improving efficiency and accelerating the transition to zero-carbon cars and trucks are crucial for fully realizing the emission reduction potential of the transport sector. Transport emission reduction has several co-benefits for the sustainable development goals such as improved health through air pollution reduction, resource efficiency, and land and water pollution from fossil fuel extraction and consumption (Dagnachew, Hof et al. 2021).

The buildings sector offers significant mitigation potential, especially in cost-effective scenarios. In 2020, buildings were responsible for just over 8.2 Gt $CO_2$ emissions, of which 67% are from indirect emissions such as electricity and heating. With current policies, $CO_2$ emissions in the building sector are projected to decrease slightly to 8 Gt $CO_2$ by 2050. In the Ext_NDC scenario, these emissions are projected to decline to 6.8 Gt $CO_2$ by 2050. The final energy demand in the sector grows from 120 EJ in 2020 to 150 EJ. High-income countries are projected to decrease emissions from buildings. However, emissions in low- and middle-income countries grow rapidly. The emission reduction gains in the Ext_NDC come from improved energy efficiency in buildings and increased use of electricity in building replacing fossil fuels coupled with rapid decarbonisation in electricity production (see Figure 12).

Achieving the well-below 2 °C or 1.5 °C target requires deep cuts in $CO_2$ emissions for commercial and residential buildings. Additional policies must reduce emissions approximately by 6.5 Gt $CO_2$ relative to the Ext_NDC scenario. The global $CO_2$ emissions from buildings in the CostEff_15D scenario are almost zero due to accelerated decarbonisation of the electricity sector and the use of biofuels. The emissions reduction in the cost-effective scenarios is mainly achieved by improving the energy intensity of buildings and a rapid increase in the share of electricity, thus almost displacing fossil fuels. This is especially visible in the CostEff_15D scenario.

Enabling the implementation of conditional NDCs requires international support. The full realisation of the conditional NDCs depends mostly on access to enhanced financial resources, technology transfer and technical cooperation, and capacity-building support; availability of market-based mechanisms; and absorptive capacity of forests and other ecosystems. Carbon pricing is a necessary instrument to incentivise the shift from fossil fuels to cleaner energy sources and energy carriers, particularly in sectors that are hard to abate.

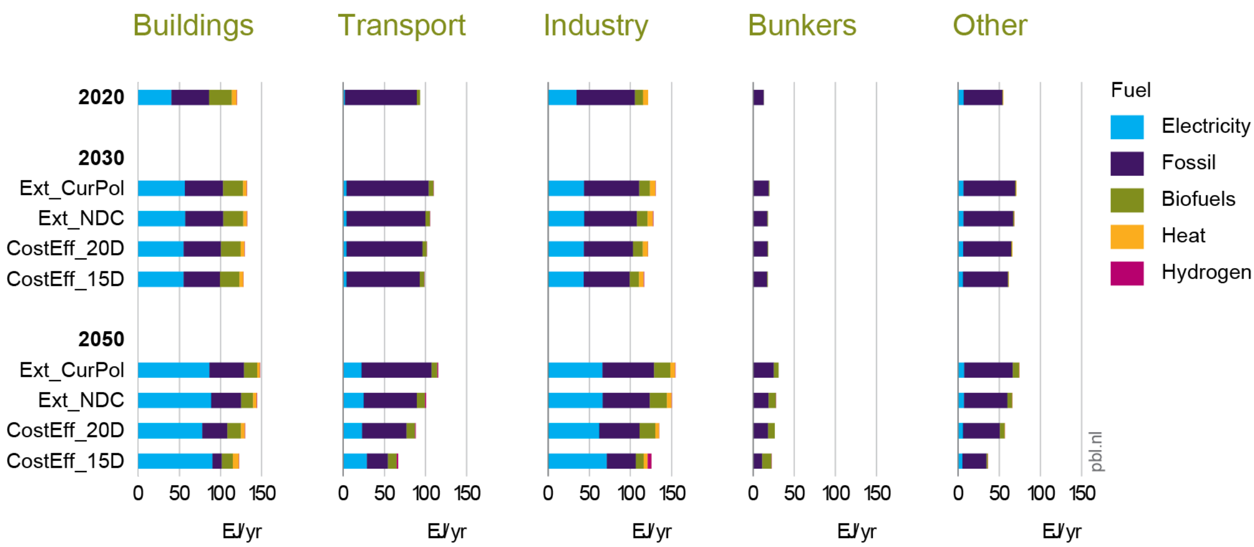


**Figure 12**
Global final energy mix by sector and fuel

## 4.2.2 Brazil

The AFOLU sector plays a crucial role in Brazil's overall emissions profile and offers significant potential for reduction. The $CO_2$ emissions in this sector are the result of deforestation and negative emissions (sinks) from reforestation and forest management (see Figure 13). Deforestation remains a challenge in Brazil, both driven by domestic and international demand for agricultural products (Haddad, Araújo et al. 2024). The sector's $CO_2$ emissions in 2020 as reported by IMAGE accounted for around 50% of $CO_2$ emissions, which is around 650 Mt $CO_2$. Estimates for land use $CO_2$ emissions are very uncertain as different reporting standards are used (see Box 1). They vary between 135 and 400 Mt $CO_2$ for bookkeeping models in the Global Carbon Project dataset (Friedlingstein, O'Sullivan et al. 2023), while the accounting methods from FAO (2024) report 385 Mt $CO_2$. Under the Ext_CurPol scenario, these emissions are projected to increase both in absolute terms and in share of emissions. In 2050, AFOLU $CO_2$ accounts for 65% of total $CO_2$ emissions in Brazil, increasing from 650 Mt $CO_2$ in 2020 to 1,000 Mt $CO_2$ in 2050. In both the 2 °C and 1.5 °C scenarios, AFOLU $CO_2$ emissions are projected to become a carbon sink in 2050, driven by halted deforestation and expanding tree planting efforts.

Although $CO_2$ emissions cover almost 75% of total GHG emissions globally, this only constitutes 40% in Brazil. This can be attributed to the country being the fourth-largest producer of agricultural products in the world by value. In 2020, GHG emissions from agriculture accounted for almost 40% of Brazil's total GHG emissions. Together, $CH_4$ and $N_2O$ agricultural emissions accounted for 630 Mt $CO_2e$ (based on GWP-100 accounting). Most of these emissions come from enteric fermentation that deserves special attention to tackle the growing emissions from agriculture. Animal waste management, synthetic nitrogen fertilisers, irrigated rice cultivation, and residue incineration also contribute to agricultural emissions in Brazil (Veiga, Popin et al. 2024). The emissions decrease by around 60% between 2020 and 2050 in the current policies and NDC scenarios, and only decrease slightly more, around 70%, in the 2 °C and 1.5 °C scenario. The model output shows that agricultural non-$CO_2$ emissions are hard to abate. Selective breeding is one way of reducing $CH_4$ emissions from enteric fermentation with co-benefits such as resource efficiency, reduced water demand, and reversing land-degradation and deforestation (Dagnachew, Hof et al. 2021).

Electricity production is expected to undergo significant changes between 2020 and 2050, despite its limited direct impact on overall emissions reduction in Brazil. Electricity production plays a limited direct role because both hydropower and biomass already account for a high share of current power generation. Hydropower represented more than 60% of electricity production in 2020, while biomass represented 10% in 2020. By 2050, the emissions from electricity production are projected to decrease by 95% between 2020 and 2050 in the 2 °C scenario, and become fully negative in the 1.5 °C scenario.

The transport sector was the second highest emitting sector in 2020 and is positioned for significant reductions between 2020 and 2050. This sector accounts for more than 30% of the total $CO_2$ emissions in 2020 (direct and indirect). The emissions decline in absolute terms and are projected to account for slightly more than 5% of the total $CO_2$ emissions in the Ext_CurPol scenario by 2050 and 8.5% in the Ext_NDC scenario. The $CO_2$ emissions in the transport sector decline in absolute terms despite the increase in final energy demand as high shares of ethanol and electricity as transport fuel reduce the role of fossil fuels in the sector. In the 2 °C and 1.5 °C scenario, $CO_2$ transport emissions are projected to reduce by 80% to 90% between 2020 and 2050. Electrification already plays a role in $CO_2$ reduction between 2020 and 2050 in the current policies scenario, while the additional reductions in the cost-effective mitigation scenarios are mostly realised by biofuels.

The industry sector in Brazil is currently a minor contributor to $CO_2$ emissions, but its emissions are expected to significantly increase by 2050. In 2020, this sector accounted for slightly more than 10%

of total $CO_2$ emissions (direct, indirect, and process emissions). However, the sector is the only one projected to see an increase in absolute emissions between 2020 and 2050 in the Ext_CurPol scenario. It increases more than threefold between 2020 and 2050 and is projected to be the second-highest emitting sector, contributing nearly a fifth of total $CO_2$ emissions by 2050. In the Ext_NDC scenario, the industry sector emissions are projected to be only slightly lower by 2050 compared to the SSP2_END scenario. Although total $CO_2$ emissions in Brazil become negative by 2050 in the 2 °C and 1.5 °C scenario, the (direct and indirect) industry emissions increase between 2020 and 2050 in the 2 °C scenario and only decrease by 25% in the 1.5 °C scenario.

The commercial and residential buildings account for less than 10% of the total $CO_2$ emissions in 2020, and that share is projected to decrease to 2% by 2050 as a result of halving total $CO_2$ emissions in this sector.

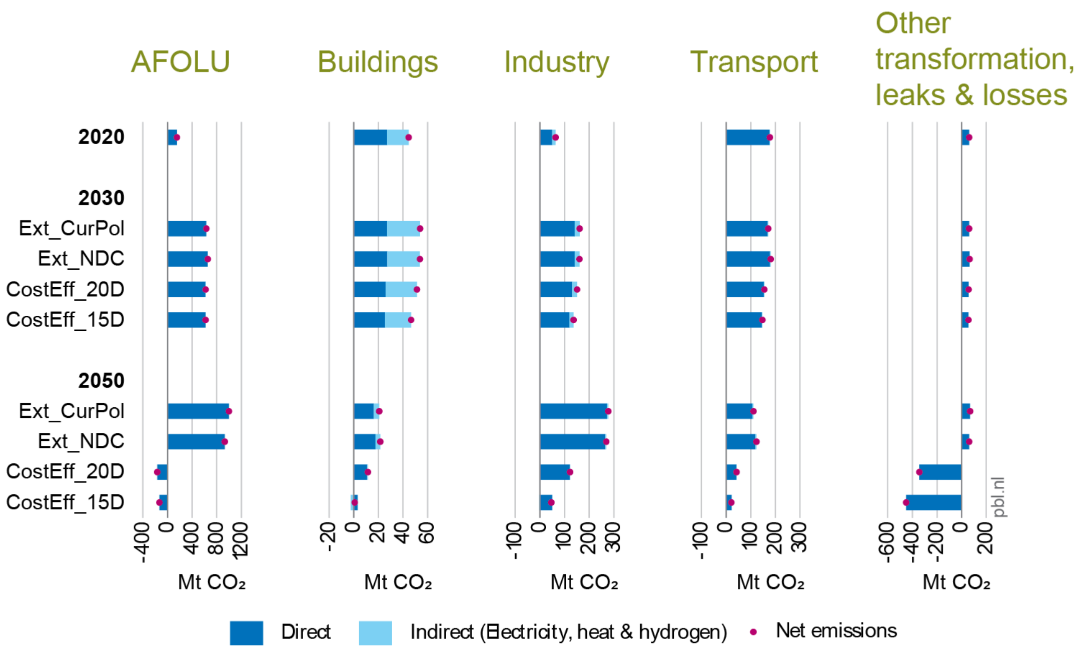


**Figure 13**
Sectoral $CO_2$ emissions in Brazil, including indirect emissions from electricity, heat and hydrogen

*Note: Large negative emissions from fuel extraction and processing come from biofuel production with CCS*

## 4.2.3 Indonesia

The AFOLU sector in Indonesia is by far the largest source of emissions, but also holds significant potential for emissions reduction. In 2020, it represented almost 65% of total $CO_2$ emissions (see Figure 14). A substantial driver of AFOLU $CO_2$ emissions is the expansion of agriculture and logging. For example, Busch, Amarjargal et al. (2022) show that if the EU had banned high-deforestation palm oil between 2000 and 2015, they could have reduced GHG emissions by 21 Mt $CO_2$ per year. Therefore, the AFOLU sector plays a significant role in emissions reduction in Indonesia. In the Ext_CurPol scenario, the AFOLU emissions decline by almost 75%, still accounting for 25% of total $CO_2$ emissions by 2050. The picture is similar in the Ext_NDC scenario as the impact on $CO_2$ emissions of NDCs is projected to be similar to current policies. The AFOLU $CO_2$ emissions in the CostEff_20D and CostEff_15D scenario are projected to reduce by almost 95% between 2020 and

2050. AFOLU does not only contribute to emissions reduction, but it compensates for the increase in other sectors like transport.

The electricity sector in Indonesia is a major contributor to current $CO_2$ emissions, highlighting the need for major decarbonisation through renewables and energy. Despite the pledge to phase out domestic coal use by 2040, the production and export of coal reached a record high in 2023. In 2020, the major source for electricity production was coal and gas, which represent 60% and 15% of total electricity production, respectively. Nevertheless, the share of low-carbon electricity sources in the Ext_CurPol scenario increases from 20% in 2020 to more than 90% in 2050, accounting for the majority of the four-fold increase in electricity production. In addition, the share of electricity use in the final energy mix in this scenario is projected to increase from more than 15% in 2020 to almost 30% by 2050 (see Figure 14).

According to the IESR, Energiewende et al. (2021) study, it is technically and economically possible to completely decarbonise Indonesia's energy system with 100% renewable energy by 2050. This is possible due to a combination of factors such as falling solar PV prices, rapid decline of electrolyser costs, and high solar potential of the archipelago. The potential of the electricity sector is also reflected in the sectoral emissions from our model outputs, which shows increasing efficiency and electricity taking over from fossil fuels. In both the 2 °C and 1.5 °C scenario, $CO_2$ emissions in the electricity production sector are projected to become negative after 2040 (see Figure 14). As a result, total emissions by 2050 in the 2 °C pathway, including indirect emissions, for the transport, buildings, and industry sectors also become negative, except for the transport sector.

The IESR, Energiewende et al. (2021) study also shows that the electrification of transport and most industry sectors plays an important role in reducing GHG emissions. This is visible in our model results where total emissions by 2050, including indirect emissions, for the buildings and industry sectors become negative in the CostEff_20D and CostEff_15D scenarios. In these pathways, competition between fossil fuels, hydrogen, and electricity in the transport sector will remain apparent by 2050. In the 2 °C scenario, the only large competitor for fossil fuels is electricity, with a market share of 10% of total energy demand of the sector, while this is projected to be 30% in the 1.5 °C scenario.

In the building sector, the electricity share will increase between 2020 and 2050 from 35% to approximately 75% in the current policies, NDC, and 2 °C scenarios, while it increases to 85% in the 1.5 °C scenarios. At the same time, the share of traditional biofuels hardly changes in this period.

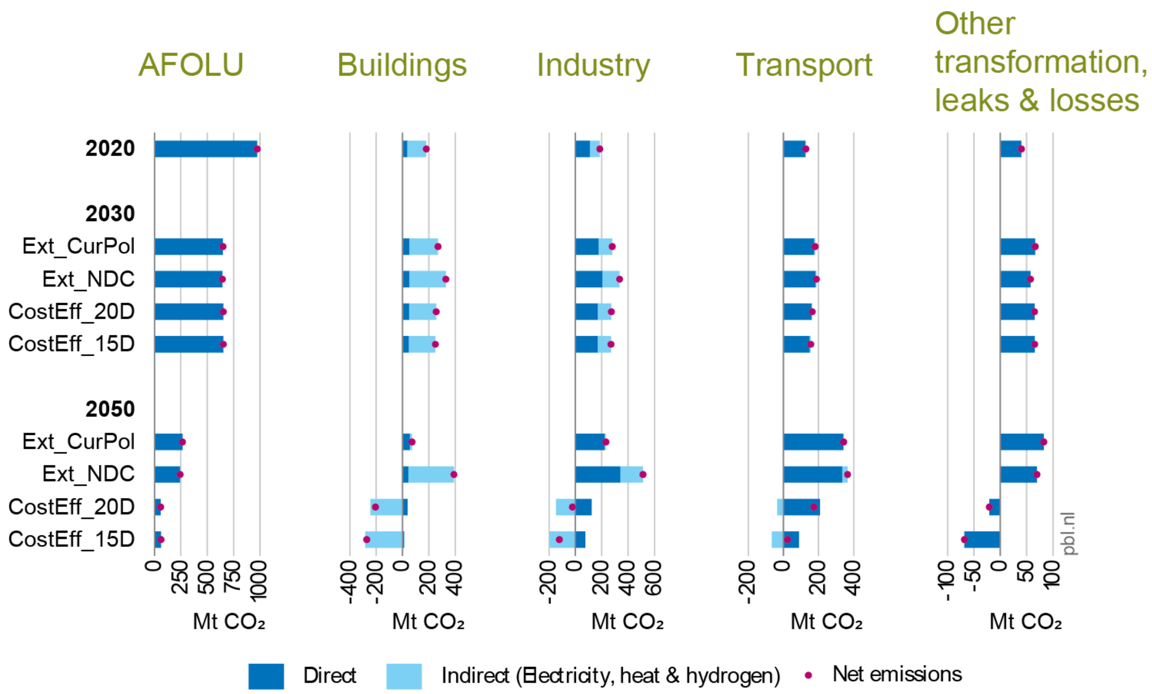


**Figure 14**
Sectoral $CO_2$ emissions in Indonesia including indirect emissions from electricity, heat and hydrogen

### 4.2.4 South Africa

South Africa currently relies heavily on fossil fuels, primarily coal, which accounted for 71% of the total energy supply in 2022 (IEA 2023a). To address this, the country launched the Just Energy Transition Partnership to attract climate finance and accelerate the coal phase-out. However, it is still too early to gauge its successes and plans have been delayed (Fakir 2023).

The electricity sector significantly contributes to $CO_2$ emissions in South Africa, and while projections suggest that electricity consumption could double between 2020 and 2050, the use of coal is projected to decrease significantly in the cost-effective scenarios. In 2020, electricity is mostly used in the industry sector (around 55%) and the buildings sector (around 40%). This share is projected to change only slightly by 2050 across all scenarios. At the same time, total electricity consumption in the current policies scenario increases between 2020 and 2050 by 85% in the industry sector and 135% in the building sector. This increase is 125% in the 1.5 °C for industry, while it is around the same for the buildings sector. Although total electricity consumption only changes marginally, the share of fossil fuels (mainly coal) in electricity production is projected to decrease significantly - from 90% in 2020 to around 20% in the 2 °C cost-effective scenario (CostEff_20D) and to 1% in the 1.5 C cost-effective scenario (CostEff_15D) by 2050. In the 1.5 °C scenario, Carbon Capture and Storage (CCS) accounts for 100% of electricity production with coal by 2050, compared to only 2% in the 2 °C scenario.

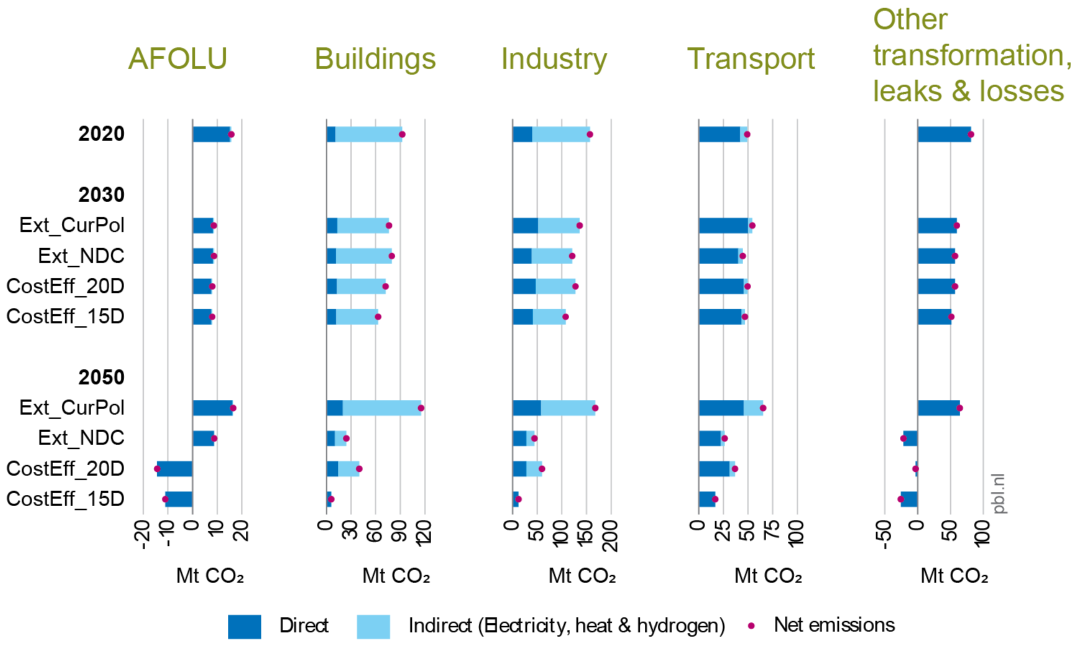


**Figure 15**
Sectoral $CO_2$ emissions in South Africa including indirect emissions from electricity, heat and hydrogen

Figure 15 shows the projected sectoral $CO_2$ emissions in South Africa in 2050. Shifts in energy consumption and production across the demand sectors is pivotal in driving significant $CO_2$ reductions in South Africa. Although total energy use in the energy demand sectors is projected to slightly change between 2020 and 2050 in the cost-effective mitigation scenarios, total $CO_2$ emissions decrease significantly in this period by 70% in the 2 °C cost-effective scenario and almost 100% in the 1.5 °C scenario.

In the transport sector, (direct and indirect) $CO_2$ emissions under the Ext_CurPol scenario increase by more than 30% between 2020 and 2050. However, they decrease by 25% and 65% in the 2 °C and 1.5 °C cost-effective scenarios, respectively. This trend is similar in the buildings sector, where $CO_2$ emissions are projected to increase by 25% in the Ext_CurPol scenario and decrease by 55% and 95% in the 2 °C and 1.5 °C cost-effective scenarios, respectively. Although $CO_2$ emissions in the industry sector are projected to increase less under the SSP_ECP scenario, the 2 °C and 1.5 °C scenarios show similar decreases to the other two sectors. The strong decrease of $CO_2$ emissions in the cost-effective scenarios is primarily due to the strong increase of renewable share of electricity production between 2020 and 2050 to 70% and 95% in the 2 °C and 1.5 °C scenarios

Deforestation and land use changes in South Africa have significant implications for $CO_2$ emissions and environmental sustainability. Since 2010, South Africa has lost 12.3 thousand hectares of natural forest, reducing the total area from 3.9 million hectares in 2010, which resulted in 26 Mt $CO_2$ emissions (Global Forest Watch 2024). In addition, FAOSTAT reports that the total forest area has decreased from 17.4 million hectares to 16.9 million hectares between 2010 and 2022 (FAOSTAT 2024). A considerable proportion of forest land consists of plantation forests (Masolele, Marcos et al. 2024). However, forestry statistics differ across different institutions (Climate transform 2022).

In the model results, the AFOLU $CO_2$ represents around 5% of total $CO_2$ emissions keeps around this level between 2020 and 2050 in the Ext_CurPol scenario. However, in the cost-effective mitigation scenarios, emissions decrease significantly and become negative by 2050 in the 2 °C scenario and 1.5 °C scenario.

### 4.2.5 Western Africa (Nigeria and Senegal)

In 2022, $CO_2$ emissions from transportation and oil production (losses) in Nigeria particularly dominate in the Western Africa region. Meanwhile Senegal's industry also contributes significantly to emissions in this region (see Table 9). In contrast, the AFOLU $CO_2$ emissions in Nigeria and Senegal are relatively low (in absolute terms) compared to other countries in the region, such as the Democratic Republic of the Congo.

**Table 9**
Total $CO_2$ emissions in 2022 for Senegal, Nigeria, and the Western Africa region

| Sector | Senegal | Nigeria | Western Africa |
|---|---|---|---|
| AFOLU | 0.4 | 5.5 | 203.4 |
| Electricity supply | 3.9 | 24.0 | 53.8 |
| Transport | 3.5 | 59.7 | 108.2 |
| Buildings | 0.6 | 4.4 | 10.7 |
| Supply losses | 0.0 | 10.6 | 21.0 |
| Industry | 4.3 | 29.3 | 58.5 |
| Other sectors | 0.0 | 0.6 | 1.3 |
| TOTAL | 12.8 | 134.1 | 253.6 |

*(Sources: EDGAR (2023) for energy emissions, and Friedlingstein, O'Sullivan et al. (2023) for AFOLU emissions).*

Sectoral $CO_2$ emissions in Western Africa from direct and indirect energy use are projected to increase significantly between 2020 and 2050 in the current policies and NDC scenarios, but approach zero or even become negative in the 2 °C and 1.5 °scenarios (see Figure 16). In 2020, the AFOLU sector accounted for around 75% of the total $CO_2$ emissions in West Africa. The $CO_2$ emissions from transport, industry, fuel extraction and processing, and buildings all contributed less than 10% each.

Nationally Determined Contributions (NDCs) outline for Nigeria and Senegal their climate goals and strategies for reducing greenhouse gas emissions. Nigeria's NDC outlines a commitment to reduce emissions by 20 % unconditionally and 45% conditionally by 2030, compared to a Business-As-Usual projection of 452.7 Mt $CO_2$e. Achieving the conditional target depends on the country's development trends and current policies, while the unconditional target requires support international support in the form of finance, technology transfer, and capacity building.

Senegal's NDC, submitted in 2020, pledges to unconditionally reduce GHG emissions by 5% by 2025 and 7% by 2030 compared to a Business-As-Usual scenario. The conditional NDC target aims to reduce total GHG emissions by 23.7 in 2025 and 29.5% in 2030. Total GHG emissions between 2010 and 2030 in the business-as-usual scenario, as reported in the NDC, are projected to increase from 16.7 Mt $CO_2$e to 37.8 Mt $CO_2$e.

Nigeria's updated NDC includes mitigation measures to achieve its targets, such as a 30% renewable energy target in the central grid and an additional 13GW of off-grid capacity, though no target year is specified (Ogbonna, Nwachi et al. 2023). Sector-wide energy efficiency improvements are expected to save 2.5% of energy annually. Senegal's NDC includes capacity targets to support its unconditional NDC commitments, such as 235 MW of solar, 150 MW of wind, and 314 MW of hydro capacity by 2030. For conditional NDC commitments, these targets increase to 335 MW of solar, 250 MW of wind, and an additional 50 MW each for biomass and Concentrating Solar Power (CSP). Renewable electricity in the Ext_CurPol scenario is projected to increase from 42% in 2020 to 2050 by 2050, with an increase of approximately 85% in the 2 °C and 1.5 °C scenarios.

Nigeria faces several challenges in implementing its NDC, including limited government support for mitigation measures in the private sector, strategic interests in the fossil sector, oil market volatility, and policy inconsistencies (Noah 2024). Senegal's challenges include ensuring the affordability of electricity and addressing consumer dissatisfaction with off-grid solutions due to lower reliability and limited uptime (IEA 2023b).

Most $CO_2$ emissions (including indirect emissions) in West Africa derive from industry, transport, and fuel production. In the current policies scenario, the emissions between 2020 and 2050 in the industry, transport, and fuel production sector are projected to increase by 425%, 150%, and 300%, respectively. However, they approach zero in the cost-effective scenarios and are projected to become negative in the fuel production sector due to CCS technologies (see Figure 16).

The $CO_2$ emissions from the fuel extraction and processing sector are significant and largely the result of gas flaring associated with oil production. Although several options are available to reduce gas flaring emissions, including capturing methane emissions from oil production and using it as energy, emissions from this source are still increasing both in Western Africa and the rest of the world (World Bank 2024b). Nigeria was the fourteenth largest oil producer in 2023, and accounts for 2% of global crude oil production (EIA 2023). Nigeria has pledged to eliminate gas flaring emissions by 2030 but it remains to date one of the world's top nine flaring countries (ibid). Historically, Senegal imported most of its oil from Nigeria but has recently begun with domestic oil production (Davis and Mihalyi , IEA 2023b).

Nigeria's forest area has decreased by 9% since 2000, primarily driven by agricultural expansion and illegal conversion, which is not prioritised for enforcement by the government (Forest Trends 2022). The country pledges to enhance forest protection, reduce fuelwood harvest, and protect and restore mangrove forest ecosystems (The Federal Government of Nigeria 2021b). Similarly, Senegal aims to prevent 0.5 million hectares of deforestation, reforest 4,000 hectares per year of mangroves, and reduce areas burnt by bushfires (Government of Senegal 2020). The model results for AFOLU $CO_2$ are dominated by DRC, showing a 5% increase between 2020 and 2050 in the Ext_CurPol scenario. However, emissions decrease by around 75 – 80% in the 2 °C and 1.5 °C scenarios, resulting in negative emissions through reforestation.

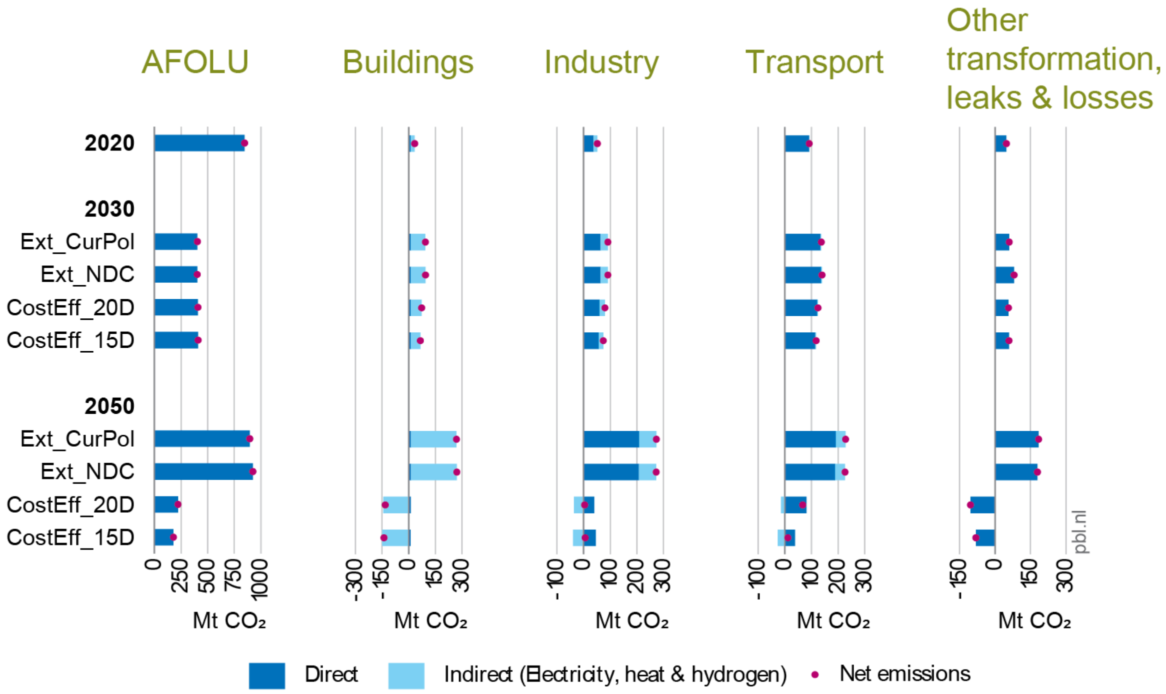


**Figure 16**
Sectoral $CO_2$ emissions in Western Africa including indirect emissions from electricity, heat, and hydrogen

*Note: Emissions from fuel extraction and processing includes biofuel production*

## 4.3 Climate damage and the costs of mitigation

As discussed in Chapter 3, climate finance assessments will have to distribute current and future financial resources across mitigation- and adaption-related implementation. Given the current context, capacities and exposure to climate impacts, each country is inclined to favour one over the other. It is important to put the cost of mitigation in the context of projected climate impacts and the benefits of avoiding these impacts that include heat-induced mortality and morbidity, labour productivity losses, agricultural productivity losses, infrastructure damages, biodiversity losses, to name a few. Depending on the regional distribution of the mitigation costs, countries may reconsider their current prioritisation of finance requirements across adaptation and mitigation. The following sections present the costs of mitigation policies and economic damage due to climate impacts globally and in selected regions.

### 4.3.1 Climate damages and costs of mitigation

Section 3.4 explored the broader context of climate mitigation costs and their significance given the committed climate damages resulting from current global warming trends. Therefore, it is important to compare the costs of global mitigation policies with the damages that can be avoided or potentially prevented under the analysed mitigation scenarios.

Global investment in clean energy has shown a steady growth in the past decade overtaking investments in fossil fuels in 2016 and accelerating further away since 2020 (IEA 2024c). IEA estimate shows that, while global energy investment exceeds USD 3 trillion in 2024, two-thirds of that investment went to clean energy technologies and infrastructure. However, the trend also shows a major imbalance between investments in advanced economies and emerging markets and developing economies, apart from China. The level of investment is also not aligned to the level required to meet the goal to limit the global temperature increase to 1.5 °C above pre-industrial level or the net-zero targets.

Figure 17 below shows the global policy cost and avoided damages under the mitigation scenarios (in 2020 USD prices). For the NDC pathway, the avoided damages evolve slowly relative to cost-effective scenarios, reaching around USD 200 billion by 2030 and doubling almost every decade after that. In relation to the policy costs, the mitigation costs slightly outweigh the benefits (avoided damages) until 2050, but the benefits increase rapidly afterwards reaching a net benefit of nearly USD 20 trillion in 2100.

The net-benefit of climate change mitigation is much bigger under the 2 °C and 1.5 °C pathways. The avoided damages are two- and three-fold relative to the NDCs in the short-term and increase to six- to nine-fold by mid-century.  For the 2 °C path, the net-benefit of climate change mitigation is about USD 100 billion in 2030 and increases exponentially to USD  67 trillion by 2100. The GDP loss under this scenario compared to the NDC path reduces from over 10% to around 3% in 2100 (as already indicated by van der Wijst, Bosello et al. (2023). For the 1.5 °C scenario, the mitigation costs remain higher than the avoided damages until about 2055 given the early and increased mitigation action in the first half of the century. Yet, the net-benefit of continued mitigation exceeds USD 4 trillion in 2050 and reaches about USD 75 trillion in 2100. The scenario shows a GDP loss of only 1,9% at the end of the century. These results indicate that a mitigation pathway aligned with the Paris Agreement will have positive effects on climate change impacts, particularly benefiting countries in Africa and Asia, which are at the highest risk.

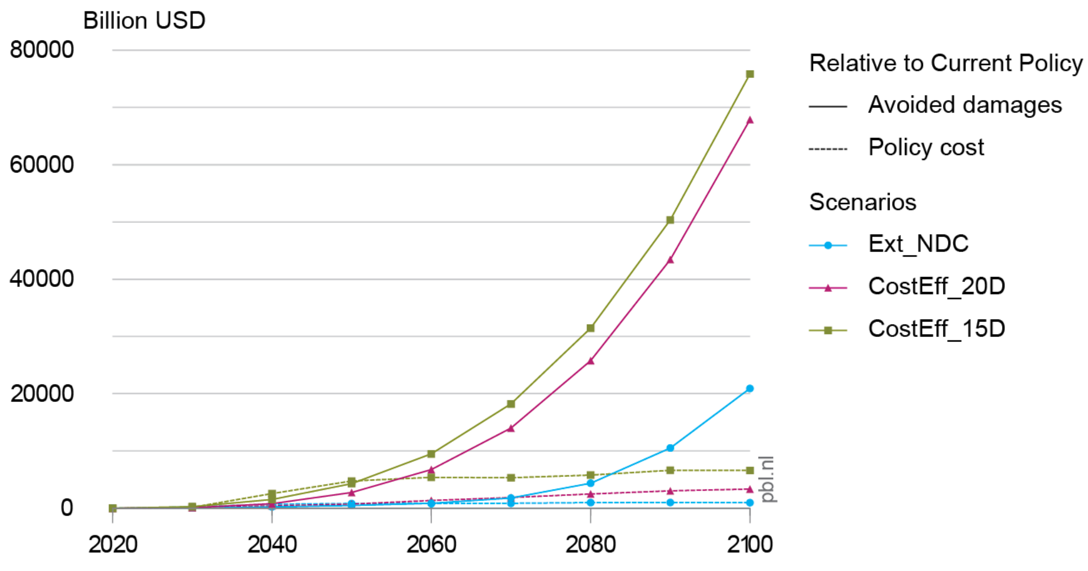


Figure 17: Global estimates of avoided damages (solid line) and policy costs (dotted line) relative to current policy (2010 USD prices)

Figure 18 presents the policy costs of the focus regions in various scenarios that result from considerable differences in mitigation ambitions and future energy demand, hence projected emissions. As can be seen under 1.5 °C and well-below 2 °C scenarios, achieving the climate targets requires a substantial increase in the current level of spending in low-carbon technologies and carbon sinks. Total cumulative policy costs between 2025 and 2050 under the well-below 2 °C and 1.5 °C scenarios amount to USD 9 and 51.4 trillion above the projected costs under the current policies scenario. This corresponds to an annual average of USD 360 billion and 2 trillion for well-below 2 °C and 1.5 °C scenarios, respectively. To put it in context, the costs amount to 0.3 – 1.1% of the average global GDP between 2020 and 2050 (189 trillion USD), a modest amount compared to the projected growth in global economy of 130% between 2020 and 2050. At the same time, innovations and investments in green technology and infrastructure could add a boost to the global economy. However, under a 1.5 °C pathway, the increase in annual policy costs will be higher between 2025 and 2040 and slows down towards 2050. The sectors with the highest policy costs requirements will be AFOLU, transport, industry and energy supply. The total policy cost for each sector vary depending on the unit cost of each mitigation measure. For AFOLU, a range of low-cost mitigation options are available (e.g. agroforestry, soil carbon management, and sustainable livestock practices) with considerable emission reduction potential.

It is evident that the 1.5 °C pathway needs an acceleration of mitigation investments globally in the near term (15 – 20 years) and especially for regions like Indonesia, South Africa, and Western Africa. If implementation follows current policies and investments, it will become increasingly difficult to bridge the gap with the Extended NDCs and well-below 2-degree-aligned pathways (as the projected cumulative policy costs gap reaches around USD 13 trillion for the Extended NDC ambitions and 9 trillion for the well-below 2 °C ambition in 2050). Emissions gap in various scenarios as discussed in the previous sections also result in finance gaps of different magnitudes in the focus regions and countries.

### 4.3.2 Brazil

Brazil faces a rapidly widening policy costs gap in the period 2030 – 2050 between current policy and the scenarios with higher ambitions. To comply with the 1.5 °C climate pathway, Brazil needs an estimated USD 14.6 billion for mitigation policy costs between 2025 and 2030. This requirement further increases to USD 994 billion by 2050 to remain on the 1.5 °C path.

As shown in the emission gap analysis, significant emission reductions under the 1.5 °C scenario must occur in the AFOLU sector, which is expected to become a net emissions sink by 2050, both under the 1.5 °C and well-below 2 °C pathways. Even under current policies, a substantial portion of $CO_2$ emission reductions is happening in the AFOLU sector. Beyond existing land-use practices, investments in the agricultural sector and strategies such as livestock and fertiliser management offer major opportunities for overall greenhouse gas emission reductions.

Additionally, significant investments in electrification and efficiency technologies are necessary for the transport and industry sectors to reduce emissions, despite increasing energy demands. Higher contributions from biomass, wind, and solar energy in electricity generation are also crucial for driving emission reductions.

For the 2 °C pathway, the policy costs gap is about 34% smaller compared to the 1.5 °C pathway. Despite the recent doubling of climate finance in land-use sectors from 2020 to 2023, substantial scaling-up is needed post-2025 to align with the 2 °C path, requiring more than USD 11 billion by

2030. Brazil's current NDC target does not represent a significant increase in ambition thus entails no substantial additional policy costs compared to current policies. Continuing with current ambition levels over the next decade or two will delay emission reductions, making it increasingly difficult to adhere to the 2 °C or 1.5 °C limits. This strongly indicates that Brazil would need to significantly increase its NDC ambition for 2030 and 2035, along with related investment commitments, to keep the well-below 2 °C target viable until 2100.

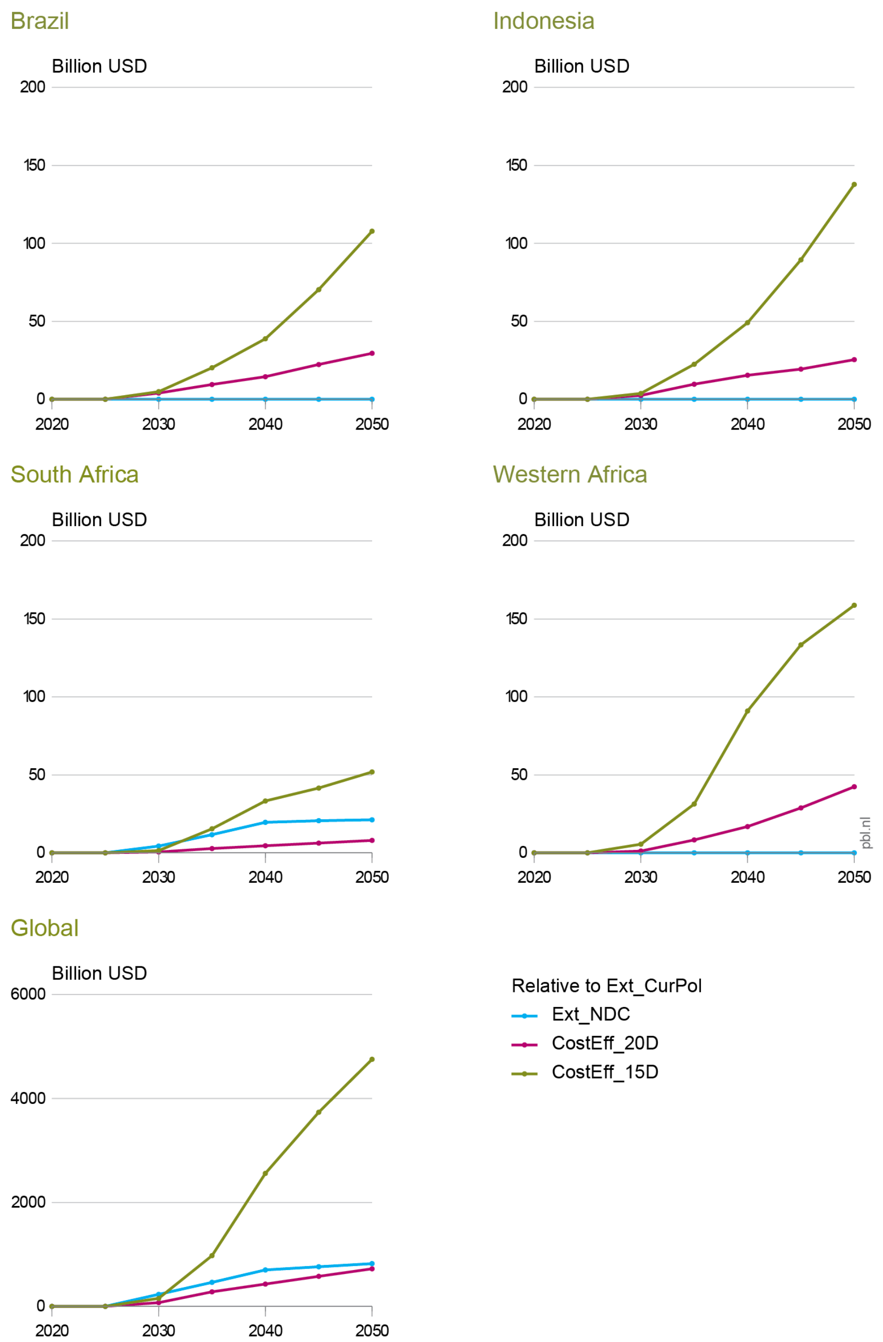


**Figure 18**
Estimated additional regional policy costs above the current policy scenario

### 4.3.3 Indonesia

As discussed in sections 4.1 and 4.2, the policy scenarios remain far behind the cost-effective scenarios in terms of emissions reductions. While the regional policy scenarios partially align with the 2°C fair-share allocation, a substantial implementation and ambition gap remains toward achieving the 1.5°C targe. Indonesia's policy cost gap between current policy and achieving the 1.5 °C climate pathway is projected to grow considerably, from over USD 11 billion in the period 2025 – 2030 to nearly USD 1 trillion in the period 2030 – 2050. This increase is largely driven by major socio-economic developments, including a population growth to 308 million by 2050 and a projected 250% economic growth compared to 2020 levels. The projected cumulative additional policy costs under the well-below 2 °C pathway amount to USD 310 billion between 2025 and 2050.

Despite the projected climate damages, Indonesia's NDC pathway does not indicate a change in mitigation ambition towards the Paris Agreement, suggesting that substantial increases in ambition are necessary. As outlined in section 4.2, significant mitigation efforts and investments should focus on the AFOLU sector. Specifically, reducing the deforestation that is often driven by agriculture expansion and logging, could unlock up to 75% emissions reduction potential by 2050 under the Ext_CurPol scenario, and even up to 95% under the CostEff_15D scenario. Additionally, electrification and efficiency improvements in the industry, buildings, and transport sectors are crucial, with hydrogen fuel expected to play a significantly larger role in the transport sector by 2050.

### 4.3.4 South Africa

South Africa faces a substantial gap in cumulative policy costs between the Ext_CurPol and Ext_NDC scenarios, amounting to USD 13 billion between 2025 and 2030 and over USD 340 billion between 2025 and 2050. This gap begins to diminish beyond 2050 as South Africa's Extended NDC scenario performs better in terms of emissions reduction compared to the cost-effective well-below 2 °C scenario. To align with the 1.5 °C pathway, South Africa requires an additional USD 4.3 billion in the period 2025 – 2030 and an additional USD 600 billion in the period 2030 – 2050, on top of current policy costs. The policy costs gap from South Africa's current policy level to a well-below 2 °C pathway is considerably smaller, amounting to USD 94 billion between 2025 and 2050. The region generally needs accelerated early investment in mitigation efforts, especially until 2040, to ensure that the growth of total policy costs slows down after this period.

With costs totalling over USD 340 billion between 2025 and 2050, the policy costs of the Extended NDC scenario are higher than those of the cost-effective well-below 2 °C pathway. The same holds true for the emission reduction ambitions across the two scenarios. Therefore, the additional finance needed on top of the NDC costs to align South Africa with the Paris Agreement requires a relatively attainable effort from a cost-effective global finance perspective.

As highlighted in the emission gap analysis, investment strategies should focus on transitioning the energy system and economy away from fossil fuels, particularly coal. This transition should include substituting coal with gas, combined with CCS, and rapidly increasing the share of nuclear and renewables in the primary energy supply to enhance electricity generation and energy security. Additionally, the AFOLU sector holds significant mitigation potential and should be expanded to contribute to achieving negative emissions, especially under a 1.5 °C pathway.

### 4.3.5 Western Africa (Nigeria and Senegal)

The additional policy costs in Western Africa needed to stay on the 1.5 °C pathway starts from a modest USD 16.5 billion in the period 2025 – 2030 and grows rapidly to USD 1.8 trillion between 2030 and 2050. In contrast, the gap between the Extended Current Policy costs and the well-below 2 °C pathway is just a quarter of the policy costs of the 1.5 °C scenario. Similar to Indonesia, the Ext_NDC pathway of Western Africa does not differ markedly from the Ext_CurPol pathway and does not require additional investments, showing the limited ambition of the current NDC targets.

While Nigeria makes up the dominant share in economic activity in Western Africa, its share dropped from 62,7% in 2022 to 54,6% in 2023 (EBID 2024). Though economic development might slightly slow down in the near future, the country remains one of the strongest economies in Africa. It will therefore be a crucial actor in leveraging investment for low-carbon technologies and fossil-fuel phase-out in the region. Especially emissions from oil production and transport are key hurdles in the region's low-carbon development and require a smooth transition towards renewable energy.

In 2019/20, Nigeria's share of West Africa's regional climate finance was 27% (Stout, Gupta et al. 2022). As mentioned in its updated NDC, the goal is to achieve 30% renewables in the central grid and employ several energy efficiency measures. The government itself estimates an annual requirement of 17.7 billion to deliver on its conditional NDC targets by 2030. Current (2019/2020) climate finance levels of USD 1.9 billion are far from reaching this target (Stout, Gupta et al. 2022). Hence, Nigeria will play one of the most crucial roles in tackling the emission reduction ambition gap in the region and could lead by example to generate finance for mitigation efforts.

Key strategies for Nigeria include the transition to a low-carbon economy, improving the overall energy efficiency, expanding electricity generation capacity, and improving energy security. The above-mentioned Energy Transition Plan (ETP) lays out the key sectoral emission reduction strategies and related (economic) development targets (The Federal Government of Nigeria 2021c). According to this plan, to achieve net-zero emissions by 2060 a total of USD 1.9 trillion is required. This includes a USD 410 billion estimated budget for Nigeria's critical energy needs, or approximately USD 10 billion per year (Okoh and Okpanachi 2023).

In 2020, Senegal contributed approximately 5% of West Africa's regional emissions, significantly less than Nigeria. However, as discussed earlier, Senegal plays a crucial role in enhancing mitigation and adaptation efforts in the AFOLU sector. By 2050, under the 1.5°C scenario, this sector can serve as a vital carbon sink, offering a highly cost-effective mitigation option. Additionally, Senegal's potential for renewable energy, including biomass, underscores the importance of focusing its energy transition efforts on improving energy accessibility and security (Diop 2022). The (renewable) energy and grid system currently present in Senegal is not yet fully developed, which presents a cost-effective opportunity for climate change mitigation, as it does not require a significant transition away from fossil fuels.

# 5 Sensitivity analysis

In this chapter we present the results of the sensitivity analysis to demonstrate how input data, assumptions, or model parameters impact the outcomes of our research. This will increase the robustness and reliability of policy-relevant conclusions.

## 5.1 Impacts of socio-economic projection on emissions and investment

In this section, we assess how uncertainties in socio-economic pathways affect emissions projections and technology choices. For this purpose, we compare the results of the projections presented in the previous chapters that are based on SSP2 with the projections based on SSP1 – 'the sustainability - Green Road'. Table 10 presents the difference between SSP1 and SSP2.

**Table 10**
Socio-economic characteristics of SSP1 and SSP2

| Socio-economic variable | SSP1 | SSP2 |
|---|---|---|
| Global GDP PPP (2010 USD) | Higher GDP per capita due to sustainable economic growth and reduced inequalities, reaching 290 trillion by 2050 and 620 trillion in 2100 | Also high GDP growth with persistent income disparities between countries, reaches 265 trillion by 2050 and 610 trillion in 2100 |
| Global population (people) | Peaks at approximately 9 billion between 2050 and 2060, then declines to around 8 billion by 2100 | Continues to grow, reaching around 9.6 billion by 2050 and approximately 10 billion by 2100 |
| Urbanization rate | High urbanization rates, with a significant majority of the population living in urban areas, 77% in 2050 and 92% in 2100 | Moderate urbanization rates, with urban population reaching around 67% by 2050 and increasing to 79% in 2100 |
| Emissions | Aims for net-zero $CO_2$ emissions around 2050, and maintains net-zero or negative $CO_2$ emissions | Emissions continue to rise until mid-century before stabilizing or declining, but not as rapidly as in SSP1 |

### 5.1.1 Global primary energy mix

Figure 19 presents the role of fossil fuels and renewables in primary energy supply under the SSP1 and SSP2 socio-economic projections for both current policies and cost-effective 1.5-degree scenarios. SSP1 scenarios have lower primary energy demand due to strong energy efficiency improvements and rapid electrification. In the current policies scenario, SSP2 has higher total primary energy supply, significantly higher fossil fuel consumption, both with and without CCS, compared to SSP1, in 2050. The role of renewable energy grows rapidly in SSP1, surpassing SSP2 by a considerable margin by 2100. SSP1 sees a decline in nuclear energy usage, whereas SSP2 maintains a moderate increase. Biomass (both with and without CCS) grows in both scenarios but remains slightly more prominent in SSP2.

The picture is quite different in the cost-effective 1.5-degree scenario. While the total primary energy supply in SSP1 in 2100 is 25% lower than in SSP2, the additional primary energy in the SSP2 comes from various energy sources with nuclear and solar providing most of the additional supply relative to SSP1. The share of renewable energy in the total primary energy is similar between SSP1 and SSP2 cost-effective 1.5-degree scenarios.

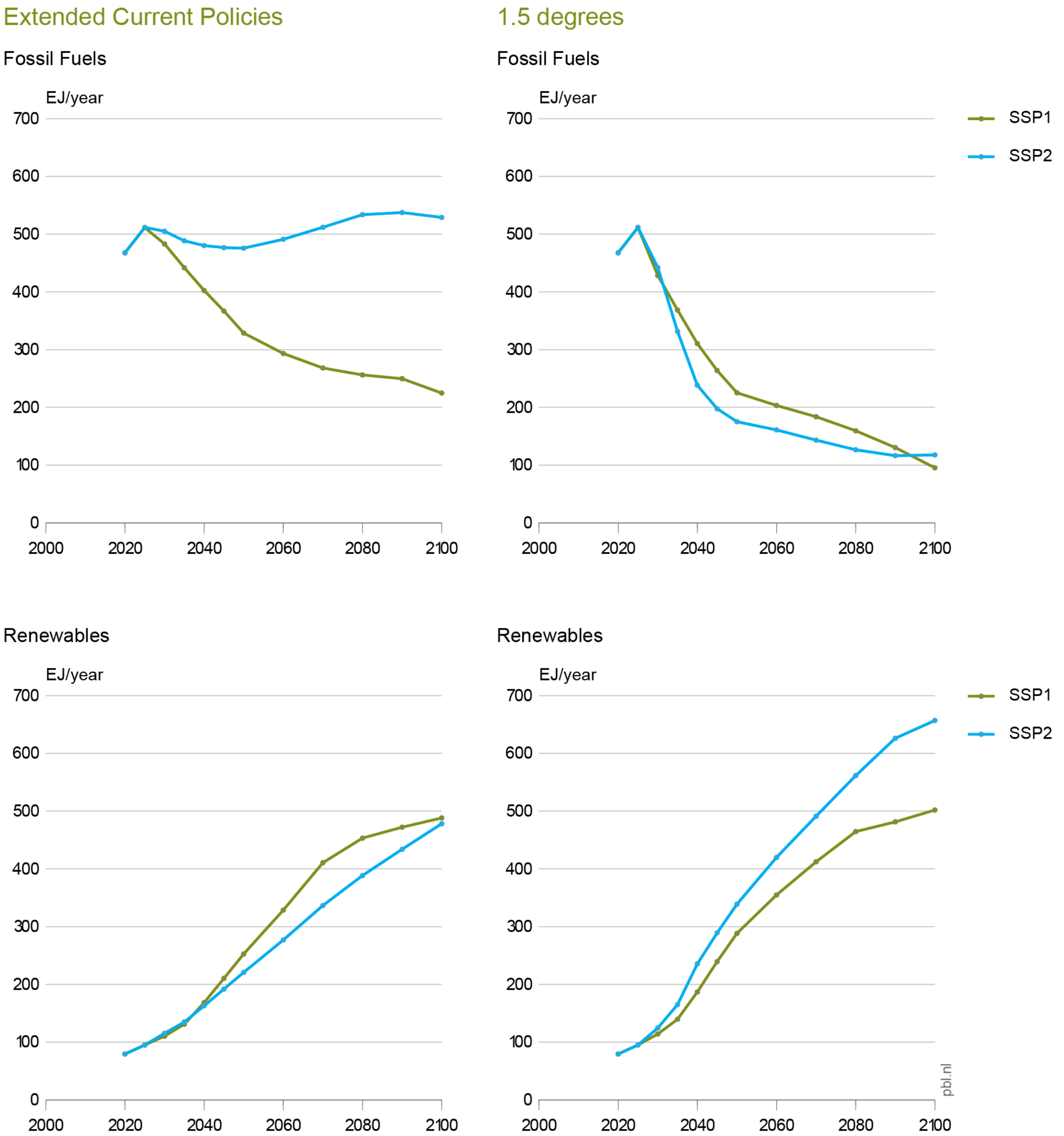


**Figure 19**
The contribution of fossil fuels and renewables in the primary energy supply

The result shows that energy demand can be decoupled from economic growth with policies that stimulate energy efficiency improvements, which could reduce primary energy demand and improve energy security. This calls for strict energy efficiency measures in various sectors, promoting demand-side management and support for research and development in energy-saving technologies. There is also the need for increased investment in renewable energy infrastructure and economic incentives for renewable energy investments and increased electrification.

### 5.1.2 Global $CO_2$ emissions

Figure 20 below presents the energy-related $CO_2$ emissions from key sectors such as electricity and heat, industry, transportation, and AFOLU at a global level. The total emissions are affected by the interaction between various assumptions, including population growth and economic development in the scenarios. The higher sustainability assumptions in SSP1 result in lower per capita and per unit GDP emissions in the Current policies scenario relative to the assumptions in SSP2. This emphasis on sustainability and the role of technologies leads to an earlier peak and subsequent rapid decline of emissions in SSP1 relative to SSP2. In both current policies and cost-effective scenarios, SSP1 shows a faster decline in total $CO_2$ emissions, though the difference with SSP2 is much higher in the former scenario. Electricity emissions decline rapidly and even go to negative before 2050 under 1.5-degree scenarios owing to the rapid shift to renewable energy and the use of CCS. Rapid improvements in efficiency and shift to cleaner technologies cut emissions from transport and industry towards mid-century in both SSP1 and SSP2 scenarios.

The SSP1 scenarios show a faster pathway to net-zero emissions. This analysis implies that net-negative emissions in power generation are critical components of effective climate change mitigation and that mitigation is more likely in the short term in SSP1 scenarios with stronger climate policies. SSP1 scenarios assume a better adoption of cleaner technologies and rapid electrification, while SSP2 emissions are influenced by slower industrial transitions and continued role of fossil fuels in the energy system. AFOLU becomes a major carbon sink in the SSP1 cost-effective 1.5-degree scenario with enhanced reforestation efforts, afforestation, and other nature-based climate change mitigation solutions. There is also a higher use of CCS in electricity production and in industry relative to SSP2. That allows a bit more room for emissions from transport and industry in until mid-century relative to SSP2.

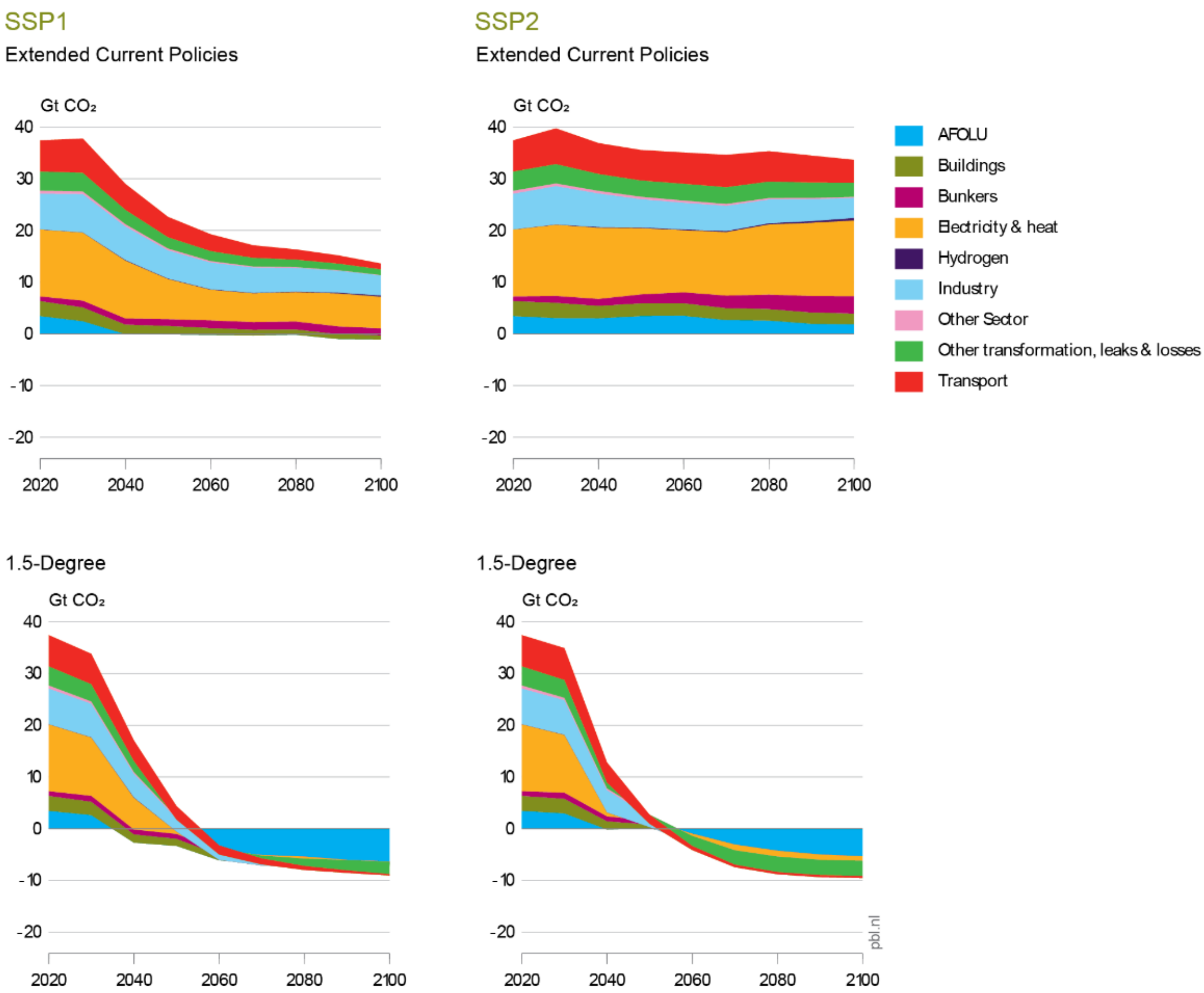


**Figure 20**
Impact of variation in socio-economic development on the global $CO_2$ emissions

## 5.1.3 Policy costs of climate change mitigation

Figure 21 below shows the projected increase of policy costs in SSP1 and SSP2 1.5-degree scenarios relative to current policies. CostEff_15D shows a rapid increase in policy cost driven by rapid population growth and a relatively slower technology development. SSP1_15D shows a steady increase in policy cost that is much lower than SSP2. The lower population growth, higher economic development, and faster advancement in technology enables climate change mitigation at lower costs compared to SSP2. The annual policy costs of reaching the 1.5-degree climate target in SSP2 is 75 – 90% more than what is required under SSP1 1.5-degree scenario between 2030 and 2100.

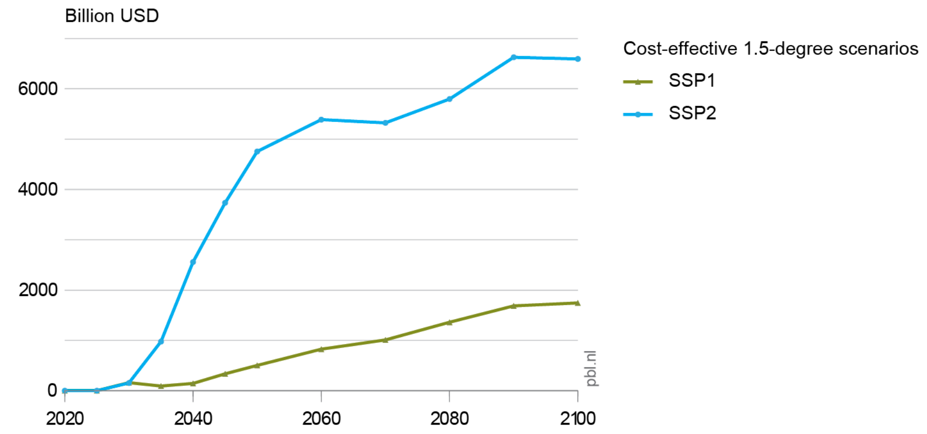


**Figure 21**
Additional policy costs for climate change mitigation in SSP2 and SSP1 1.5-degree scenarios

Here, we focused on the comparison between SSP1 and SSP2. The current trend of power competition, regional conflict, economic uncertainty, and the rise of populism and nationalism is similar to the fragmented worldview described in SSP3. The withdrawal of the United States from climate agreements could have significant repercussions on global climate targets. As a leading global emitter and financial contributor, the US plays a crucial role in international climate efforts. Its absence could weaken diplomatic momentum and reduce funding for key adaptation and mitigation initiatives, especially in LMICs. However, SSP3 presents significant challenges in achieving the 1.5 or 2-degree targets set by the Paris Agreement. The main problem is the lack of international cooperation, which undermines collective efforts to mitigate climate change. Moreover, SSP3 is marked by limited technology advancement and slower economic growth, both of which impede the development and implementation of sustainable solutions. Together, these factors make it difficult to establish a pathway that is consistent with the Paris Agreement.

## 5.2 Impact of the regional cost of capital on emissions and investment

The cost of capital in emerging and developing economies remains significantly higher than in developed economies, which is a significant barrier to energy investment. Region- and country-specific risk factors as well as technology-specific factors contribute to the high discount rate in emerging and developing economies. In our analysis, the weighted average cost of capital (WACC) is used as a discount rate for investments. The costs of technologies are affected by the regional discount rates applied in the model (see Appendix 1). Discount rates vary from just over 4% in North America to 9% and more in South Asia and Central America. Higher discount rates make technologies with high capital investments with low operating expenditures more expensive than technologies that require low capital investment with higher operating expenditures (van der Welle, Halstead et al. 2023).

Few studies using Integrated-Assessment-Model (IAM)-based scenarios have integrated differentiated cost of capital assumptions and show that decarbonisation pathways are halted or slowed down in regions with higher discount rates (Ameli, Dessens et al. 2021, Calcaterra, Aleluia Reis et al. 2024). Calcaterra, Aleluia Reis et al. (2024) show that this leads to lower green electricity generation, lower globally-cost-effective deployment of renewables and hence, a slower rate of emission reduction, particularly in Africa. In turn, high discount rates increase the total investment costs required for mitigation in Africa. Ameli, Dessens et al. (2021) refer to this as the climate investment trap for economically weak or risky country contexts: their higher cost of capital delays or halts climate investments and causes further delays decarbonisation. This then adds to a higher finance gap. One of the options to halt these climate investment traps is to focus on policies that reduce WACC differences in the short- to medium-term. National measures that reduce the average discount rate can either be related to the choice of technologies or the improvement of country-related financing conditions. International measures to reduce the discount rate in LMICs can involve guarantees from richer countries or from financial institutions such as the World Bank or the Global Environment Facility.

Calcaterra, Aleluia Reis et al. (2024) provide the capital cost (WACC) for electricity generation that include country risk and technology risk. The authors compare the average capital cost for fossil fuel-based power generation and hydro, and the capital cost for non-hydro-based renewable energy. The capital cost for fossil fuel-based power generation are derived from the financing cost of a major set of energy utilities (balance sheet finance). For hydro, the cost of capital is driven by the specific country, sector level, and technology level discount rates (i.e. project finance). The findings show that developed countries have the lowest WACC values, while industrialised Asian countries have lower WACC values than other low- and middle-income countries. In our standard runs, WACC for all countries is determined by using a flat interest rate of 10%. This assumption does not reflect the current financial conditions, nor does it account for differences in country and technology risks. For sensitivity analysis, we adopt the 'CoC-convergence' scenario by Calcaterra, Aleluia Reis et al. (2024) where the regional cost of capital in LMICs converges linearly to that of Europe and USA by 2050. This is arguably an idealised scenario that is meant to show the effects of equal access and capabilities to finance. This does not suggest that climate action should be delayed until the cost of capital is low. Climate change impacts are already happening, and postponing action would exacerbate these effects, making future mitigation efforts more challenging and costly. What it actually implies is that international cooperation in technology transfer, financial support, and effective governance can empower LMICs to implement timely and effective climate strategies. At the same time, we show an alternative scenario where the WACC values of LMICs converge to the low values of Europe and USA a century later, i.e. by 2150, which represents a slower convergence across countries in terms of their country risk factors. By applying this WACC-convergence idea, Calcaterra, Aleluia Reis et al. (2024) assume that every country in the end has equal access to energy finance and that policies that promote international risk pooling and global diversification are put in place. Collective policy measures like green bonds, risk guarantees, and international financing (both donations and soft loans) can help to reduce the finance gap in low- and middle-income countries. The WACC values for each region are presented in Table 12 of Appendix 1.

### 5.2.1 Regional primary energy mix

Figure 22 below outlines regional projections of different primary energy sources under various scenarios, illustrating the evolving role of fossil fuels, renewables, and nuclear energy in the global energy mix. All scenarios entail the least costs pathway to meet the 1.5 degree climate target but using different discount rates. Under all three scenarios, fossil fuels are projected to peak before 2030 and sharply decline afterwards. The projections indicate a steeper decline in the use of fossil fuels without carbon capture and storage (CCS) in the long term with regional discount rates (SSP2_SlowConv and SSP2_FastConv) compared to the flat discount rate of 10% in the CostEff_15D scenario. The scenario with a fast convergence in regional WACCs shows the highest relative growth in renewable energy among the three scenarios, particularly in Brazil and Western Africa where there is significant unexploited solar potential. Similarly, in Indonesia, the lower discount rates result in an increase in wind energy in the medium and long term. In South Africa, the falling discount rates result in an increase in the shares of biomass and nuclear energy in the long term. These results demonstrate that, even though the impact is modest, lower cost of capital accelerates the displacement of fossil fuels with low-carbon energy sources, particularly solar and wind.

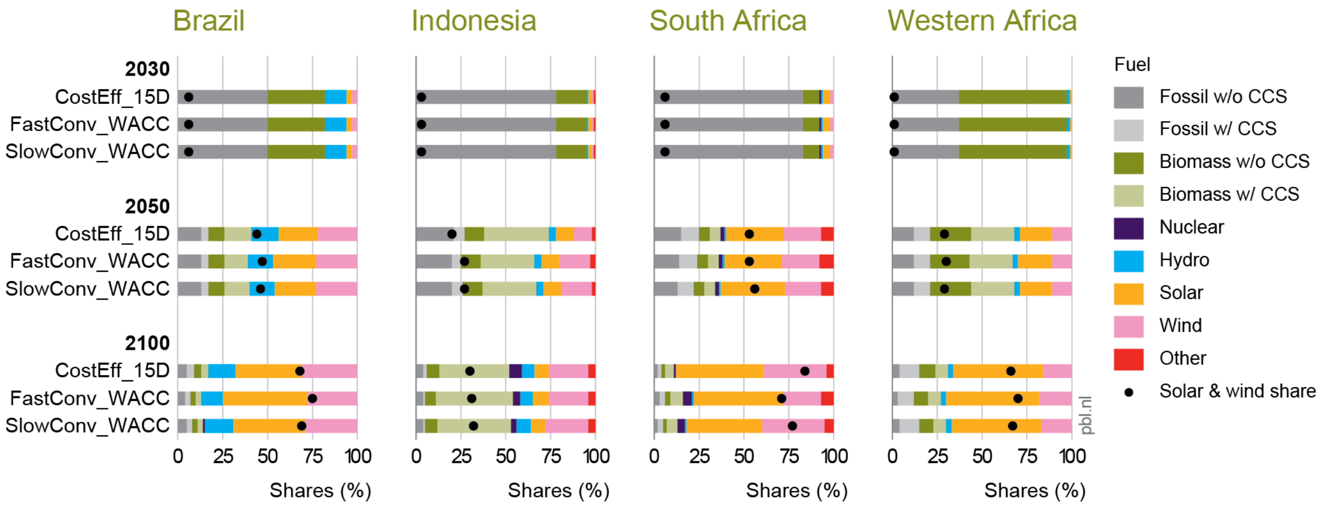


**Figure 22**
Regional primary energy mix with varying WACC

Rapidly converging regional discount rates reduce the costs of financing renewable energy projects, making them cheaper relative to fossil fuels in low- and middle-income regions, such as Brazil, Indonesia, and Western Africa. This is because renewable energy requires more upfront investments. Hence, investment in renewable energy is more sensitive to changes in financing costs than investments in fossil fuel-based plants. Lower discount rates lead to a higher share of renewables in the primary energy mix. A lower cost of capital also make it easier to invest in battery storage, pumped hydro, and smart grids, addressing intermittency challenges.

On the other hand, fossil fuel plants have higher fuel and operational costs, making them less sensitive to lower discount rates compared to renewables. However, if renewables become cheaper to finance, new coal and gas investments decline, leading to a lower share of fossil fuels in the primary energy mix, as demonstrated in Indonesia. Some gas-fired power plants remain due to their flexibility in balancing intermittent renewables, but overall growth slows down.

## 5.2.2 Regional electricity technology mix

Global renewable electricity grows across all scenarios, reaching 230 – 245 EJ per year by 2050, which gives a major shift in the total share of renewables. As shown in Figure 23, with fast converging regional discount rates, the share of electricity generation from solar and wind increases by nearly 2 and 7 percentage-points relative to CostEff_15D scenario in Brazil and Indonesia, respectively. While the reduction in discount rates stimulate investments in nuclear energy in South Africa, it has little impact in Western Africa's electricity system as electricity generation is already dominated by solar, wind and hydro in the CostEff_15D scenario. The share of electricity generation from fossil fuels declines rapidly in all scenarios by mid-century. Global net electricity production increases by 3 – 8 percentage-points in the slow and fast WACC convergence scenarios compared to the default WACC scenario by 2100. This increase is a result of a decrease in electricity prices due to lower marginal cost in most of low- and middle-income regions due to lower cost of capital.

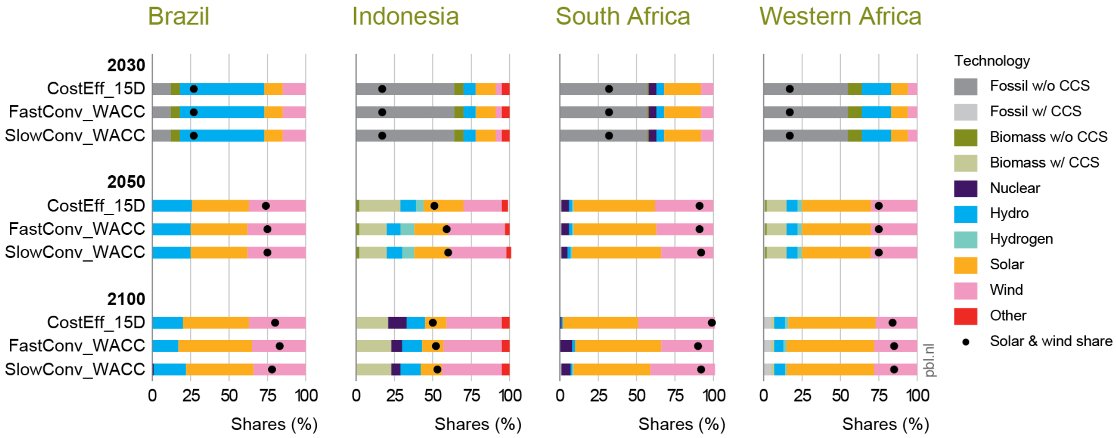


**Figure 23**
Regional electricity mix with varying WACC

## 5.2.3 Regional sectoral $CO_2$ emissions

Figure 24 below illustrates the impact of varying Weighted Average Cost of Capital (WACC) on regional sectoral $CO_2$ emissions. The region-specific capital cost demonstrates a considerable reduction in $CO_2$ emissions from AFOLU, buildings, and transport in Brazil by 2050, compared to the constant WACC scenario. The rapidly converging discount rate indicates an even greater potential for emissions reduction, ranging from 2% in electricity and heat production to 15% in AFOLU relative to the slow convergence scenario. In Indonesia, the building and transport sectors benefit from the reduction in discount rates, with $CO_2$ emissions in 2050 being 30% and 7% lower in the FastConv_WACC scenario for buildings and transport, respectively, compared to the constant WACC scenario. South Africa also sees benefits from WACC convergence, with emissions from buildings declining by 25 – 30% and in transport 10 – 11% by 2050 under both the slow and fast WACC convergence scenarios, relative to the constant discount rate. In Western Africa, there is a decline in $CO_2$ emissions in the AFOLU and transport sectors as discount rates decrease.

This is a result of lower low-carbon technology investment hindered by the high risk of investment in these regions leading to a high cost of capital in the short term. As the regional WACCs converge to the low values of EU and US by 2050, higher investments in low-carbon technologies and a rapid phase-out of carbon intensive technologies in the economy lead to lower levels of GHG emissions, reducing the need for carbon removal technologies. The impact is evident in buildings and power sectors where there are low-carbon alternatives readily available to replace traditional carbon-intensive technologies and processes.

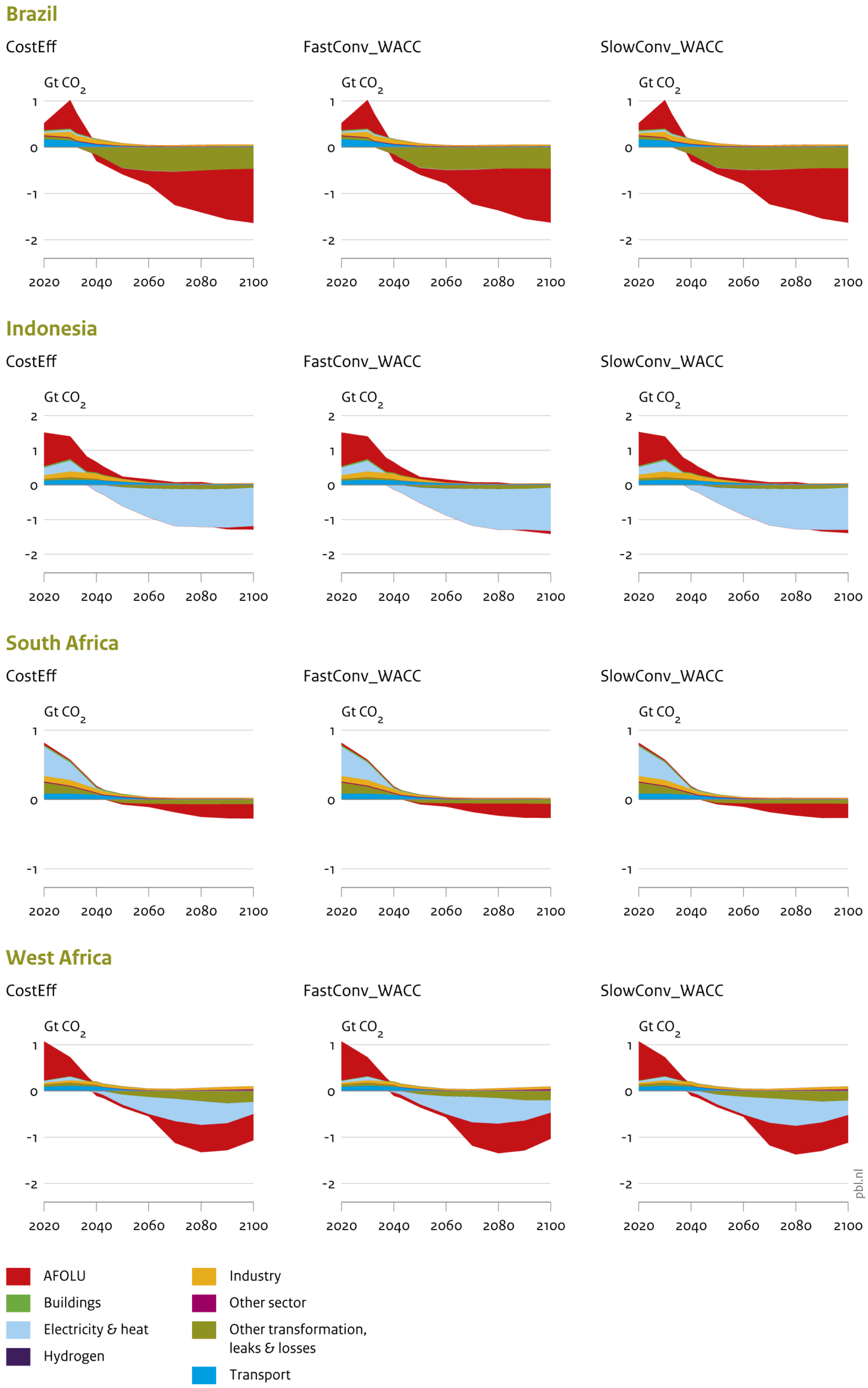


**Figure 24**
Regional sectoral $CO_2$ emissions with varying WACC

### 5.2.4 The policy cost of climate change mitigation

A lower discount rate plays a crucial role in reducing the total costs of climate mitigation efforts, making large-scale investments more financially viable. Expanding the power grid, developing electric vehicle charging infrastructure, and ramping up hydrogen production all require significant capital, and a high discount rate can make these projects prohibitively expensive. As illustrated in Figure 25, the decrease in the cost of capital in LMICs has an immediate effect on cumulative policy costs, with savings ranging from 8% in Brazil to 40% in Indonesia. By 2050, Brazil's cumulative policy costs of climate change mitigation are projected to exceed USD 150 billion in the CostEff_15D scenario, decreasing to USD 142 billion and USD 140 billion in the SlowCov_WACC and FastConv_WACC scenarios, respectively. Indonesia sees the greatest benefit from a reduced cost of capital, with cumulative policy costs falling from USD 190 billion with constant WACC to USD 130 – 133 in the WACC convergence scenarios by 2050. South Africa and Western Africa also benefit from WACC convergence, with the cumulative policy costs in 2050 dropping by 10 – 12 % in South Africa and 7 – 10 % in Western Africa relative to the constant discount rate.

Rapid WACC convergence encourages investment in low-carbon solutions such as renewables, energy storage, and nuclear power, ultimately driving down overall system costs by replacing costly fossil fuels in the long-term. In the short-term towards 2040, these amounts hardly differ from the reference scenario of a uniform 10% WACC across all regions and technologies. In that sense, the 10% seems like a representative, average estimate for a current global WACC rate. However, the global policy costs vary towards mid-century and after under a regional variable WACC than in the scenario with a uniform WACC. The period of convergence did not have a significant difference, both for regional and global policy costs since all three scenarios have to meet the 1.5-degree target cost-effectively. It goes beyond the scope of this analysis to study the exact effect sizes of improved technology-specific WACC representation and it could well be that specific technology or policy instruments may strengthen the impact of a lower WACC.

Overall, it is evident that for low- and middle-income countries, lower capital costs can be a gamechanger, allowing them to shift toward sustainable energy faster and more efficiently. This can accelerate the transition to electrification in transportation, heating, and industry, making clean energy more accessible and affordable. In essence, reducing WACC is not just about financial optimisation—it is a key enabler of a cost-effective and equitable global energy transition.

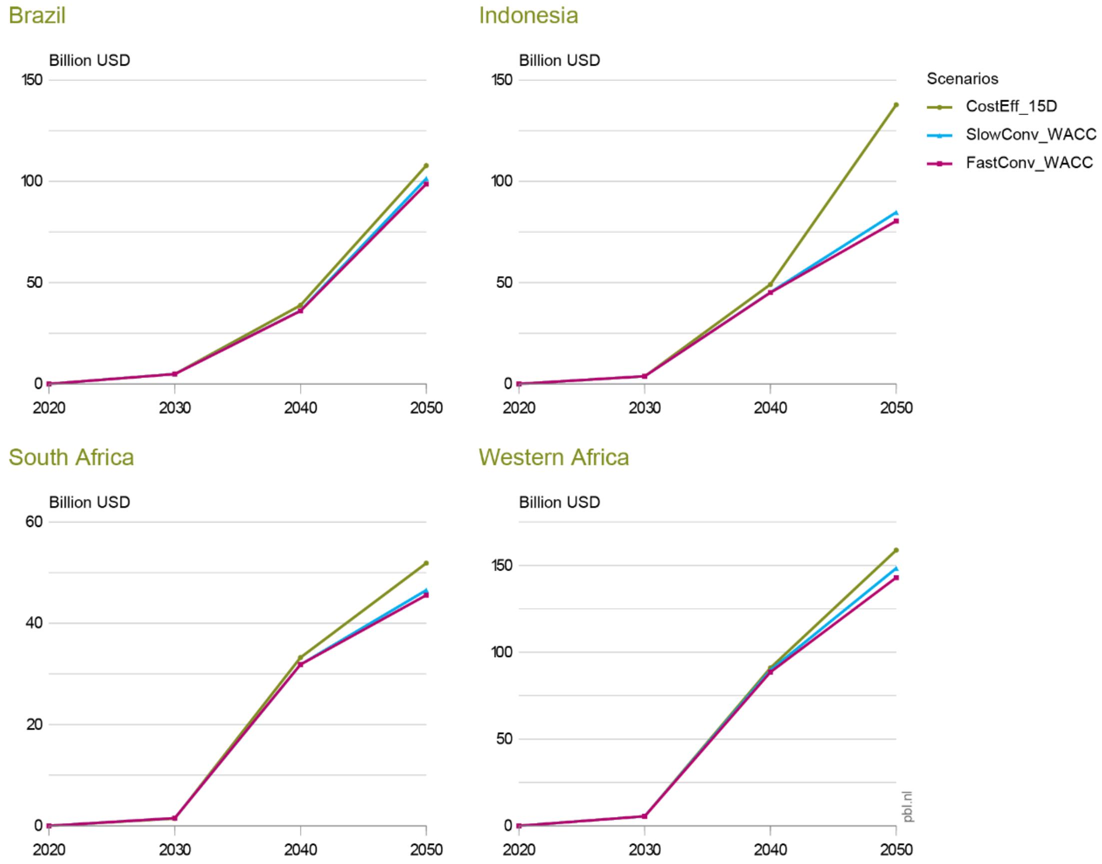


**Figure 25**
Global mitigation policy cost with varying WACC

# 6 Reflections: Policy pathways and justice

In this report we employed scenario analysis to explore the emissions gap and the policy cost gap between current policies and NDCs and what is needed to limit global temperature increase to 2-degree and 1.5-degree Celsius by the end of the century. We also provided insight into the role of main economic sectors in achieving these climate targets. In conducting this analysis, we utilised a single Integrated Assessment Model (IAM), IMAGE, as a primary tool in our projections for most of the scenarios. While IAMs are powerful tools for exploring complex interactions between economic, environmental, and social systems, relying on a single model introduces a degree of uncertainty to the findings. Each IAM has inherent assumptions and limitations that can influence outcomes, and these may not fully capture the breadth of possible scenarios or account for unforeseen variables. This is reflected in this report where we made comparisons with other similar studies in relevant sections, highlighting where differences in model assumptions and methodologies may lead to variations in findings.

Part of these uncertainties are addressed by varying the socio-economic projection, the speed of technology advancement, and the assumed regional discount rates (or cost of capital). However, there are other uncertainties that could affect the results of our projection, including uncertainties in energy demand and consumption patterns, policy and governance effectiveness, behavioural and lifestyle changes, uncertainties in the climate system, to name a few. It is not possible to remove all uncertainties from future projections; hence, the results should be interpreted with these uncertainties in mind. Despite these uncertainties, the results of our study give important insight into the regional priorities in climate change mitigation, the role of sectors and technologies in climate change mitigation, and the magnitude of the emission and finance gaps in LMICs in the short-, medium- and long-term.

## 6.1 Mitigation pathways and their implications

This report presents model results for current policies, NDCs, and cost-effective pathways towards meeting climate targets for LMICs and puts the results in the context of effort-sharing pathways. Together, these scenarios provide a comprehensive view of current policies (Business-As-Usual), the policy ambitions (NDCs), and optimal pathways to meet global climate targets. The scenarios have different goals and show different levels of emission mitigation as well as different roles of sectors and technologies. The associated mitigation costs also vary with the strictness of the mitigation pathway.

The current policies scenario explores a trajectory of GHGs under existing and implemented policies, without considering future policy changes or additional commitments. This scenario also serves as a benchmark for understanding what additional policies and strengthening of ambitions are required to meet the climate targets. Assessing existing policies and their implementation allows identifying the emission and finance gaps between the current collective global actions and the cost-effective pathway towards the Paris Agreement to keep global temperature increase well below 2 °C. The comparison between existing and documented policy actions and the pathway towards the Paris targets helps policymakers to identify areas where further policy action is needed. The main outcome of this analysis is that current policies are insufficient to address the challenge and the emission and the finance gaps with the pathway to limit global temperature increase are large and growing. However, the assumptions that these policies will remain in place, fails to capture the dynamic policy environments where existing policies are enhanced or rolled back.

Our NDC scenario is an additional policy scenario that reflects the emission trajectories and mitigation actions that countries have committed to under the Paris Agreement. The NDC scenario stipulates the collective impact of these pledges on global GHG emissions and the resulting temperature outcome. This specific scenario is a critical reference point for assessing the emission gap between the Business-As-Usual trend and the pathway to meet the ambition to limit global temperature increase to well-below 2 °C. The strength of the NDCs lies in their comprehensive country- and sector-specific commitments that allows for resource allocation and international comparison. The NDCs are updated every five years which allows to identify new policy directions and emerging mitigation strategies that reflect the growing ambitions of nations. However, there are still challenges with the NDC-based scenarios. Collectively, the NDCs, even if fully implemented, still fall short of the pathway to keep the temperature increase well-below 2 °C. The lack of clarity to the countries' ambitions beyond 2030 also makes it difficult to compare emission pathways in the long term. Moreover, some NDCs lack quantified targets or rely on not-clear policy intentions that cause uncertain interpretations or assumptions in modelling.

Cost-effective scenarios model pathways for the most economically-effective trajectory to achieving the 1.5 °C and well-below 2 °C targets. These cost-effective scenarios prioritise measures with the lowest marginal costs and minimise the global total costs of achieving agreed global temperature targets, while considering all available mitigation options that are feasible with the economy-wide carbon price. These scenarios do not reflect the political or institutional constraints but instead focus on what is technically and economically feasible. The least cost scenarios direct resources to mitigation measures with the highest impact. The scenarios cover all major sectors and provide insights into sectoral trade-offs. Future innovations and cost reductions in nascent technologies play a role in determining mitigation options and related future policy costs. These scenarios, however, ignore (geo-)political realities, institutional barriers, and the difficulty of implementing ambitious globally coordinated carbon pricing. There is also a reliance in these scenarios on rapid technology breakthrough, for instance Bioenergy with Carbon Capture and Storage (BECCS), as major mitigation options. The role of negative emissions in these mitigation pathways might also distract policymakers from crucial near-term actions. The scenarios assume a global least cost pathway and ignores the development priorities in and the disproportional cost burden on LMICs that suffer the most from climate change. At the same time, these scenarios can be used to guide international resource coordination to capture mitigation options with the highest impact.

The fair-share scenarios—Per Capita Convergence, Ability to Pay, and Equal Cumulative Per Capita—each provide distinct moral frameworks for equitably distributing the responsibility of GHG emissions reduction among countries. The Per Capita Convergence scenario aims for equal emissions per capita by a specific target date. This allows lower-income countries to increase their emissions in the short-term and reduce later, while wealthier countries reduce theirs already in the short-term, promoting long-term equity. However, this approach may prove to be difficult for high-emission nations to meet the convergence target in the short term, given the current high emissions levels. The Ability to Pay scenario assigns a greater burden to wealthier nations as emission reductions are inversely related to GDP per capita of the countries, leveraging the economic capacity of rich countries to take on more ambitious emissions reduction commitments. Its main disadvantage, however, lies in the potentially high financial burden on wealthier countries. The Equal Cumulative Per Capita scenario aims for an equal allocation of emission rights over time, factoring in historical emissions. While it addresses past inequalities, it may require complex and extensive negotiations. Each of these moral frameworks promotes fairness and equity in global climate policy, but each also presents its own set of challenges that require international cooperation and consensus for successful implementation.

To summarise, the current policies scenarios reflect the Business-As-Usual path that is highly insufficient to achieving global climate goals. The NDC scenarios show a step forward but still require substantial enhancement to limit warming to well below 2 °C. The cost-effective scenarios offer an economically optimal trajectory but ignore or underestimate other important factors related to political feasibility, equity, and availability of certain technologies. Limiting global warming to well below 2 °C relative to pre-industrial levels requires enhanced NDC ambitions, scaling up innovation and climate finance, technical and human capacity building in LMICs, and ensuring a just transition.

## 6.2 Justice-based reflection on NDCs

The question remains, however, how do justice considerations impact the formulation and implementation of NDCs in the context of global climate governance, particularly for LMICs? Justice is an increasingly prominent topic in global sustainability agendas. Attention for equity, responsibility, and burden-sharing is widespread in multilateral climate policy frameworks, for example through the UNFCCC's principle of common but differentiated responsibilities and respective capabilities (CBDR-RC), as well as in ongoing discussions on climate finance, and loss and damage. In this study, we have included effort-sharing principles for the mere purpose of putting the policy and cost-effective scenarios in a context of fairness. These effort-sharing scenarios are policy frameworks that distribute the responsibility of reducing GHG emissions among different countries or regions taking historical emissions, remaining emission budget, economic capability and future responsibilities into account. While our effort-sharing scenarios are about allocating climate mitigation efforts among countries based on different fairness criteria, climate justice is a broader ethical and political concept that includes mitigation, adaptation, loss and damage, and socio-economic justice.

Against this backdrop, NDCs can be seen not only as technical mitigation plans but also as tools through which to engage with broader justice-related considerations, such as who bears the costs of climate action, which groups have the capacity to contribute to the design and implementation of climate policy, and how historical and structural factors shape national commitments.
The relevance of justice for the NDCs of developing countries can be understood in two main ways. First, justice can be embedded as a normative goal within NDCs: NDCs can be instruments for the pursuit of development agendas if they integrate key just transition elements such as meaningful participation in dialogue, social protection, and economic diversification alongside emissions reductions commitments (Antwi-Agyei, Dougill et al. 2018). Second, justice can serve as an analytical lens through which interrogate the structural constraints developing countries might face

in designing and implementing their NDCs, as well as the global power imbalances that shape the broader global climate governance regime.

### 6.2.1 Justice within NDCs: Embedding just transition principles in national climate policy

A just transition is one where the shift towards a zero-carbon economy also promotes inclusive human development (i.e. ensures all people - especially marginalised and vulnerable communities - benefit from climate action while having the opportunity to participate in decision-making) and restores natural ecosystems (Oates and Verveld 2024). It is particularly pertinent in the context of developing countries, where addressing socioeconomic issues like poverty, inequality, and job creation is as pressing as climate action (Lee and Baumgartner 2022).

To date, just transition principles remain relatively rare in developing countries' domestic climate strategies, including in NDCs (Glynn, Błachowicz et al. 2020), due in part to a lack of consensus on what constitutes a just transition and the absence of practical guidance on implementation. Developing countries require international support to implement justice-oriented climate policies. NDCs that explicitly address just transition can help secure climate finance, technology transfer, and capacity-building assistance.

Explicitly incorporating justice-related aspects into NDCs can help mitigate any negative consequences of climate action, promote sustainable and inclusive economic opportunities, and align climate action with broader development priorities. For example, a key concern is the participation of affected communities in climate policymaking, particularly marginalised groups such as Indigenous peoples, rural and informal workers, women, migrants, and ethnic minorities. Embedding the rights of vulnerable groups in NDCs can be a step towards ensuring that they are not disproportionately impacted by climate policy (Pucheta, Álvarez Alonso et al. 2021) and can instead generate co-benefits, such as improved livelihoods and economic diversification.

### 6.2.2 Justice beyond NDCs: Structural challenges and historical responsibility

Beyond their content, the very existence of NDCs raises justice-related questions about global climate governance. Structural inequalities, rooted in historical disparities, shape the ability of developing countries to set and implement ambitious climate commitments, as well as the broader context in which these commitments are made. Many developing countries face financial, technological, and institutional constraints that limit their capacity to carry out climate action at the same pace as developed countries that are disproportionately responsible for past and present emissions.

The current round of NDCs is crucial for keeping the Paris Agreement's 1.5 °C target within reach, but in all scenarios, all regions must accelerate mitigation efforts to align with both well-below 2 °C and 1.5 °C pathways by 2050. In our cost-effective scenarios (CostEff_20D and CostEff_15D), the most effective mitigation opportunities are often concentrated in developing countries.

An intergenerational justice perspective might advocate for taking all necessary actions to meet climate targets, as delays increase the risk of severe climate impacts and, in turn, the associated justice concerns. However, stringent emissions reductions based on cost-optimal allocation approaches may create challenges for just implementation at the national level (van Vuuren, van Dam et al. 2024). Increasingly, rights-based approaches are seen as delivering more effective and legitimate outcomes in the longer term (IPCC 2022).

At the same time, many developing countries depend on financial and technological support to achieve ambitious climate targets (Dash and Gim 2019, Mehrotra and Benjamin 2022), often structured as loans (rather than grants) that risk increasing debt burdens (IIED 2024), or technology transfers that favour foreign investment over place-based solutions that enable local capacity building and technological sovereignty (Oates, Kasaija et al. 2023).

A more critical perspective argues that NDCs exist within a system of carbon-intensive development built on the exploitation of human and natural resources in developing countries (Escobar 2015). Despite contributing little to historical emissions, these countries now face the greatest climate risks. From this viewpoint, climate policy, including NDCs, could serve as a tool not only for achieving emissions reductions but also for addressing deeper structural injustices.
It is not within the scope of this report to provide a comprehensive account of justice considerations in NDCs, nor to make recommendations on the basis thereof. However, reflecting on justice-based discussions is essential for both contextualising the projections presented here, and recognising the limitations thereof. While the results may illustrate economically optimal pathways, not all 'fairness' considerations can be quantified (Rajamani, Jeffery et al. 2021). Moreover, by defining what is technically feasible within a limited set of modelled futures, model results can shape policy discussions and influence which political priorities receive attention (Rubiano Rivadeneira and Carton 2022). Further research could explore how justice considerations can be more fully integrated into the design and assessment of NDCs.

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# Appendices

## Appendix 1: Method and tools

### Regional groupings

**Table 11**
Regional groupings in IMAGE relevant for this report

| Region name | Countries in the region |
|---|---|
| **Brazil** | Brazil |
| **Indonesia** | Indonesia, Papua New Guinea, Timor-Leste |
| **South Africa** | South Africa |
| **Western Africa** | Benin, Burkina Faso, Cameroon, The Republic of Cabo Verde, Central African Republic, Chad, Democratic Republic of the Congo, Republic of the Congo, Cote d'Ivoire, Equatorial Guinea, Gabon, The Gambia, Ghana, Guinea Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, São Tomé and Príncipe, Senegal, Sierra Leone, Saint Helena, Ascension, Tristan da Cunha Togo |

### Regional WACC values

**Table 12**
Regional WACC values for SSP2_SlowConv and SSP2_FastConv scenarios (Calcaterra, Aleluia Reis et al. 2024)

| Region | WACC value | Region | WACC value |
|---|---|---|---|
| Canada | 4.3% | Ukraine region | 4.7% |
| USA | 4.2% | Kazakhstan region | 5.7% |
| Mexico | 4.8% | Russia | 5.8% |
| Central America | 9.7% | Middle East | 6.5% |
| Brazil | 4.3% | India | 9.1% |
| Rest South America | 6.1% | Korea region | 8.2% |
| Northern Africa | 5.5% | China | 8.0% |
| Western Africa | 8.3% | Southeast Asia | 4.8% |
| Eastern Africa | 6.3% | Indonesia | 9.0% |
| Republic of South Africa | 4.7% | Japan | 8.7% |
| Western Europe | 6.8% | Oceania | 8.9% |
| Central Europe | 5.3% | Rest of South Asia | 7.2% |
| Turkey | 5.9% | Rest of Southern Africa | 6.2% |

## Fair share allocation rules

Source: https://zenodo.org/records/14505804

1. The 'Per Capita Convergence' (PCC): This scenario emphasises the convergence of emissions per capita over time. Under this approach, countries aim to achieve similar per capita emission levels by a certain date, regardless of their current levels. It acknowledges the disparity in emissions and economic development among countries, allowing for adjustments that help poorer countries increase their emissions temporarily while wealthier countries reduce theirs more rapidly. This framework seeks to balance the emissions distribution globally on a per capita basis, promoting equity in the long term. An additional important parameter here is the year at which this convergence is complete. The country carbon budget is calculated as the portion of the remaining carbon budget allocated according to a country's share of the global population in 2021.

2. The 'Ability to Pay' (AP): This scenario is based on the principle that countries with greater economic capabilities should bear a larger share of the burden in reducing emissions. The 'ability to pay' model suggests that wealthier nations, with more resources and financial capacity, should take on more ambitious targets for emissions reduction compared to less affluent countries. This approach aligns with the idea of climate justice, where those who are more financially equipped to tackle climate change should contribute more to the mitigation efforts. This method is also dependent on the socio-economic scenario. The carbon budget is calculated by summing up all positive $CO_2$ allocations as determined by the AP rule.

3. The 'Equal Cumulative Per Capita' (ECPC): This method builds on the per-capita convergence method and also accounts for historical responsibility. It advocates for equal cumulative emissions per capita over a specified period. It suggests that every individual across the globe should have an equal right to emit a certain amount of greenhouse gases over their lifetime. This scenario considers historical emissions and aims to create a balance where the cumulative emissions of each person are equalised, addressing the disparities caused by varying levels of development and historical emissions among countries. Throughout the convergence period, countries resolve historical 'debt' or 'leftover' from what countries would have emitted if it had emissions according to a per capita share in the past. The carbon budget for ECPC represents the full-century allocation, encompassing both the historical leftover or debt and a country's equitable per capita share for the period from 2021 to 2100.

# Appendix 2: Additional model data

## Regional financing gaps

**Table 13**
Cumulative additional policy costs relative to the current policy scenario across regions (billion USD)

| Scenario | Region/Country | 2025 – 2030 | 2030 – 2050 | 2050 – 2100 |
|---|---|---|---|---|
| Ext_NDC | Brazil | 0 | 0 | 0 |
| | Indonesia | 0 | 0 | 0 |
| | South Africa | 13 | 335 | 750 |
| | Western Africa | 0 | 0 | 0 |
| | Global | 690 | 12,800 | 46,000 |
| CostEff_20D | Brazil | 12 | 330 | 4,500 |
| | Indonesia | 7 | 305 | 6,200 |
| | South Africa | 2 | 95 | 945 |
| | Western Africa | 3.5 | 400 | 8,400 |
| | Global | 215 | 8,800 | 110,000 |
| CostEff_15D | Brazil | 15 | 985 | 8,400 |
| | Indonesia | 11 | 1,230 | 11,900 |
| | South Africa | 4 | 610 | 2350 |
| | Western Africa | 17 | 1,780 | 19,500 |
| | Global | 460 | 51,000 | 290,000 |

# Appendix 3: Climate policy modelling protocol

Source: (Dafnomilis, van Soest et al. 2023)

**Table 14**
Climate policy modelling protocol for Brazil

| Brazil | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0a-BRA-GEN-NDC-25 | 220505934 | Economy-wide | NDC Emission reduction target | GHG reduction target, Political & non-binding GHG reduction target | Energy efficiency, non-energy use, Other low-carbon technologies and fuel switch, Renewables | Nationally Determined Contribution - NDC Brazil (2022) | Planned | yes | no | 2022 | 2025 |
| 0a-BRA-GEN-NDC-30 | 220505934 | Economy-wide | NDC Emission reduction target | GHG reduction target, Political & non-binding GHG reduction target | Energy efficiency, non-energy use, Other low-carbon technologies and fuel switch, Renewables | Nationally Determined Contribution - NDC Brazil (2022) | Planned | yes | no | 2022 | 2030 |
| 0a-BRA-GEN-NDC-50 | 220505934 | Economy-wide | NDC Emission reduction target | GHG reduction target, Political & non-binding GHG reduction target | Energy efficiency, non-energy use, Other low-carbon technologies and fuel switch, Renewables | Nationally Determined Contribution - NDC Brazil (2022) | Planned | yes | no | 2022 | 2050 |
| 1a-BRA-GEN-FGAS-45 | 230206065 | Economy-wide | Kigali Amendment on HFCs | Target, GHG reduction target | Energy service demand reduction and resource efficiency, non-energy use | Kigali Amendment on HFCs Brazil (2021) | Implemented | yes | yes | 2021 | 2045 |
| 4a-BRA-TRA-BIO-15 | 211001899 | Transport | National Biodiesel Programme | Obligation schemes | Renewables | National Biodiesel Programme (PNPB) Brazil (2005) | Implemented | yes | yes | 2005 | 2015 |
| 4a-BRA-TRA-BIO-19 | 211001899 | Transport | National Biodiesel Programme | Obligation schemes | Renewables | National Biodiesel Programme (PNPB) Brazil (2005) | Implemented | yes | yes | 2005 | 2019 |

| Brazil | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4a-BRA-TRA-BIO-23 | 211001899 | Transport | National Biodiesel Programme | Obligation schemes | Renewables | National Biodiesel Programme (PNPB) Brazil (2005) | Implemented | yes | yes | 2005 | 2023 |
| 4c-BRA-TRA-BIO-15 | 211001073 | Transport | Ethanol Blending Mandate | Obligation schemes | Renewables, Energy efficiency | Ethanol Blending Mandate Brazil (1993) | Implemented | yes | yes | 1993 | 2015 |
| 4d-BRA-TRA-BIO-28 | 211002557 | Transport | Biofuel carbon intensity | Green certificates, Product standards, Political & non-binding renewable energy target | Renewables | RenovaBio (Decree 9308) Brazil (2018) | Implemented | yes | yes | 2018 | 2028 |
| 4e-BRA-TRA-BIO-20 | 211105450 | Transport | Biodiesel blending | Product standards, Sectoral standards | Other low-carbon technologies and fuel switch | Changes in the biodiesel blending mandate Brazil (2020) | Implemented | no | no | 2020 | |
| 4f-BRA-TRA-BIO-23 | 211105450 | Transport | Biodiesel blending | Regulatory Instruments, Obligation schemes | Other low-carbon technologies and fuel switch | Resolution Nr 5 of June 2018 on Biofuels Brazil (2018) | Implemented | no | no | 2018 | 2023 |
| 5b-BRA-TRA-EFF-22 | 211003059 | Transport | Energy efficiency in vehicles | Tax relief, Vehicle fuel-economy and emissions standards | Energy efficiency, Other low-carbon technologies and fuel switch | Rota 2030 Mobility and Logistics Brazil (2018) | Implemented | yes | yes | 2018 | 2030 |
| 6a-BRA-BUI-LIG-16 | 211000242 | Buildings | Ban on incandescent light bulbs | Regulatory Instruments, Other mandatory requirements, Product standards | Energy efficiency | Efficient lighting policy Brazil (2010) | Implemented | yes | yes | 2016 | |
| 8a-BRA-ALU-AFF-30 | 230706213 | Agriculture and forestry | Low-Carbon Agriculture Plan (ABC+) | Policy support, Institutional creation | Non-energy use | Agricultural Policy for Climate Adaptation and Low Carbon Emission (ABC+) | Implemented | yes | no | 2023 | 2030 |
| 8b-BRA-ALU-AFF-30 | 230706213 | Agriculture and forestry | Low-Carbon Agriculture Plan (ABC+) | Policy support, Institutional creation | Non-energy use | Agricultural Policy for Climate Adaptation and Low Carbon Emission (ABC+) | Implemented | yes | no | 2023 | 2030 |

| Brazil | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8c-BRA-ALU-AFF-30 | 230706213 | Agriculture and forestry | Low-Carbon Agriculture Plan (ABC+) | Policy support, Institutional creation | Non-energy use | Agricultural Policy for Climate Adaptation and Low Carbon Emission (ABC+) | Implemented | yes | no | 2023 | 2030 |
| 10a-BRA-ENE-FOS-23 | 211105454 | Electricity and heat | Ban on flaring/venting | Regulatory Instruments, Codes and standards, Industrial air pollution standards | Energy service demand reduction and resource efficiency | Resolution No 806 of 2020 from ANP Brazil (2020) | Implemented | yes | no | 2020 | 2023 |
| 11a-BRA-ENE-REN-23 | 211105456 | Electricity and heat | Auctions | Regulatory Instruments, Fiscal or financial incentives, Feed-in tariffs or premiums | Renewables | Law 14,120/2021 on power sector Brazil (2021) | Implemented | no | no | 2021 | 2023 |
| 12a-BRA-ALU-DEF-19 | 211105462 | Agriculture and forestry | Decree | Policy support, Institutional creation | Non-energy use | Decree no 10.144 instituting the National Commission for the Reduction of GHG Emissions from Deforestation and Forest Degradation Brazil (2019) | Implemented | | Need estimate of IIASA | 2021 | |
| 12b-BRA-ALU-DEF-19 | 211105463 | Agriculture and forestry | Decree | Policy support, Institutional creation | Non-energy use | Decree no 10.142 instituting the Executive 2021 - COMMITtee for the Control of Illegal Deforestation and the Recovery of Native Vegetation Brazil (2019) | Implemented | | Need estimate of IIASA | 2021 | |

**Table 15**
Climate policy modelling protocol for Indonesia

| Indonesia | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0a-IDN-GEN-NDC-30 | 230206057 | Economy-wide | NDC Emission reduction target | Target, GHG reduction target, Political & non-binding GHG reduction target, Strategic planning | Energy efficiency, Energy service demand reduction and resource efficiency, non-energy use, Other low-carbon technologies and fuel switch, Renewables | Nationally Determined Contribution - NDC Indonesia (2022) | Planned | yes | no | 2021 | 2030 |
| 0b-IDN-GEN-NDC-30 | 230206057 | Economy-wide | NDC Emission reduction target | Target, GHG reduction target, Political & non-binding GHG reduction target, Strategic planning | Energy efficiency, Energy service demand reduction and resource efficiency, non-energy use, Other low-carbon technologies and fuel switch, Renewables | Nationally Determined Contribution - NDC Indonesia (2022) | Planned | yes | no | 2021 | 2030 |
| 0c-IDN-GEN-LTS-60 | 220205761 | Economy-wide | GHG emissions reduction | Target, GHG reduction target, Political & non-binding GHG reduction target | Policy support, Strategic planning, Target, GHG reduction target, Political & non-binding GHG reduction target | Long-Term Strategy for Low Carbon Indonesia (2021) | Planned | yes | no | 2021 | 2060 |
| 1a-IDN-ALU-DEF-20 | 211001199 | Agriculture and forestry | FLENS | Strategic planning | Energy service demand reduction and resource efficiency, non-energy use, Energy efficiency, Renewables, Other low-carbon technologies and fuel switch | Forest Law Enforcement National Strategy (FLENS) Indonesia (2005) | Implemented | yes | yes | 2005 | |
| 2a-IDN-ENE-REN-25 | 211001958 | Electricity and heat | National Energy Policy 2014 | Policy support, Strategic planning, Target, Renewable energy target, Political & non-binding | Energy efficiency, Renewables, Other low-carbon technologies and fuel | National Energy Policy (Government Regulation No. | Implemented | yes | no | 2014 | 2025 |

| Indonesia | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementati on state | Quantifia ble | IMAGE CurPol scenario inclusion | Start date of implementati on | End date of implement ation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | renewable energy target | switch, non-energy use | 79/14) Indonesia (2014) | | | | | |
| 2a-IDN-ENE-REN-50 | 211001958 | Electricity and heat | National Energy Policy 2014 | Policy support, Strategic planning, Target, Renewable energy target, Political & non-binding renewable energy target | Energy efficiency, Renewables, Other low-carbon technologies and fuel switch, non-energy use | National Energy Policy (Government Regulation No. 79/14) Indonesia (2014) | Implemented | yes | no | 2014 | 2050 |
| 2b-IDN-ENE-FOS-25 | 211001958 | Electricity and heat | National Energy Policy 2014 | Policy support, Strategic planning, Target, Renewable energy target, Political & non-binding renewable energy target | Energy efficiency, Renewables, Other low-carbon technologies and fuel switch, non-energy use | National Energy Policy (Government Regulation No. 79/14) Indonesia (2014) | Implemented | yes | no | 2014 | 2025 |
| 2b-IDN-ENE-FOS-50 | 211001958 | Electricity and heat | National Energy Policy 2014 | Policy support, Strategic planning, Target, Renewable energy target, Political & non-binding renewable energy target | Energy efficiency, Renewables, Other low-carbon technologies and fuel switch, non-energy use | National Energy Policy (Government Regulation No. 79/14) Indonesia (2014) | Implemented | yes | no | 2014 | 2050 |
| 4a-IDN-ENE-REN-30 | 211105415 | Electricity and heat | Electricity Supply Business Plan (RUPTL) | Strategic planning, Renewable energy target | Renewables | Electricity Supply Business Plan (RUPTL) Indonesia (2030) | Implemented | yes | yes | 2021 | 2030 |
| 4a-IDN-ENE-REN-50 | 211001286 | Electricity and heat | General Plan for National Energy (RUEN) Indonesia (2017) | Strategic planning, Renewable energy target | Renewables | General Plan for National Energy (RUEN) Indonesia (2017) | Implemented | yes | yes | 2017 | 2050 |
| 4b-IDN-ENE-REN-30 | 211105415 | Electricity and heat | Electricity Supply Business Plan (RUPTL) | Strategic planning, Renewable energy target | Renewables | Electricity Supply Business Plan (RUPTL) Indonesia (2030) | Implemented | yes | yes | 2021 | 2030 |
| 4b-IDN-ENE-REN-50 | 211001286 | Electricity and heat | General Plan for National Energy (RUEN) | Strategic planning, Renewable energy target | Renewables | General Plan for National Energy | Implemented | yes | yes | 2017 | 2050 |

| Indonesia | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Indonesia (2017) | | | (RUEN) Indonesia (2017) | | | | | |
| 4c-IDN-ENE-REN-30 | 211105415 | Electricity and heat | Electricity Supply Business Plan (RUPTL) | Strategic planning, Renewable energy target | Renewables | Electricity Supply Business Plan (RUPTL) Indonesia (2030) | Implemented | yes | yes | 2021 | 2030 |
| 4c-IDN-ENE-REN-50 | 211001286 | Electricity and heat | General Plan for National Energy (RUEN) Indonesia (2017) | Strategic planning, Renewable energy target | Renewables | General Plan for National Energy (RUEN) Indonesia (2017) | Implemented | yes | yes | 2017 | 2050 |
| 4d-IDN-ENE-REN-30 | 211105415 | Electricity and heat | Electricity Supply Business Plan (RUPTL) | Strategic planning, Renewable energy target | Renewables | Electricity Supply Business Plan (RUPTL) Indonesia (2030) | Implemented | yes | yes | 2021 | 2030 |
| 4d-IDN-ENE-REN-50 | 211001286 | Electricity and heat | Electricity Supply Business Plan (RUPTL) | Strategic planning, Renewable energy target | Renewables | General Plan for National Energy (RUEN) Indonesia (2017) | Implemented | yes | no | 2017 | 2050 |
| 4e-IDN-ENE-ELE-28 | 211000811 | Electricity and heat | Electricity Supply Business Plan (RUPTL) | Strategic planning, Renewable energy target | Renewables | Electricity Supply Business Plan (RUPTL) (2028) | Implemented | yes | no | 2019 | 2028 |
| 4f-IDN-ENE-EFF-25 | 211001286 | Electricity and heat | Energy consumption savings | Strategic planning, Energy efficiency target, Political & non-binding energy efficiency target, Renewable energy target, Political & non-binding renewable energy target | Energy service demand reduction and resource efficiency, Energy efficiency, Renewables, Other low-carbon technologies and fuel switch | General Plan for National Energy (RUEN) Indonesia (2017) | Implemented | yes | no | 2017 | 2025 |
| 4f-IDN-ENE-EFF-50 | 211001286 | Electricity and heat | Energy consumption savings | Strategic planning, Energy efficiency target, Political & non-binding energy efficiency target, Renewable energy target, Political & non- | Energy service demand reduction and resource efficiency, Energy efficiency, Renewables, Other low-carbon | General Plan for National Energy (RUEN) Indonesia (2017) | Implemented | yes | no | 2017 | 2050 |

| Indonesia | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | binding renewable energy target | technologies and fuel switch | | | | | | |
| 5a-IDN-ENE-FIN-12 | 211002451 | Electricity and heat | Feed-in-tariff | Feed-in tariffs or premiums | Renewables | Presidential Regulation No.112/2022 Indonesia (2022) | Implemented | no | no | 2022 | |
| 5b-IDN-ENE-FIN-12 | 211000421 | Electricity and heat | Geothermal tariff | Feed-in tariffs or premiums | Renewables | Presidential Regulation No.112/2022 Indonesia (2022) | Implemented | no | no | 2022 | |
| 6a-IDN-TRA-BIO-25 | 211000266 | Transport | Biofuel blending | Regulatory Instruments, Codes and standards, Obligation schemes | Renewables, Other low-carbon technologies and fuel switch | Ministry of Energy Regulation 12 /2015 –Mandatory Biofuel blending Indonesia (2015) | Implemented | yes | yes | 2013 | 2025 |
| 6b-IDN-TRA-BIO-25 | 211005210 | Transport | Biofuel blending (bioethanol) | Regulatory Instruments, Codes and standards, Obligation schemes | Renewables, Other low-carbon technologies and fuel switch | Raising of the biodiesel blending mandate Indonesia (2020) | Implemented | yes | no | 2020 | 2025 |
| 6c-IDN-TRA-BIO-25 | 211000266 | Transport | Biofuel blending (biodiesel) | Regulatory Instruments, Codes and standards, Obligation schemes | Renewables, Other low-carbon technologies and fuel switch | Ministry of Energy Regulation 12 /2015 –Mandatory Biofuel blending Indonesia (2015) | Implemented | yes | no | 2013 | 2025 |
| 7a-IDN-BUI-EFF-09 | 211001017 | Buildings | Appliance and equipment standards | Comparison label, Monitoring | Energy efficiency | Energy efficiency labelling Program Indonesia (2009) | Implemented | no | no | 2009 | |
| 8a-IDN-ALU-MAN-11 | 211001863 | Agriculture and forestry | Moratorium on licenses on primary forest | Regulatory Instruments | Energy service demand reduction and resource efficiency, Energy efficiency, Renewables, Other low-carbon technologies and fuel switch, non-energy use | Moratorium on the issuance of new conversion permits for primary forest and peatlands Indonesia (2011) | Implemented | yes | no | 2011 | |

| Indonesia | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 9a-IDN-TRA-EVP-19 | 211002305 | Transport | Support for electric vehicles | Fiscal or financial incentives, Strategic planning | Other low-carbon technologies and fuel switch | Presidential Regulation 55/2019 on electric vehicles Indonesia (2019) | Implemented | no | no | 2019 | |
| 9b-IDN-TRA-EVP-50 | 211205628 | Transport | Support for electric vehicles | Fiscal or financial incentives, Strategic planning | Other low-carbon technologies and fuel switch | EV tax scheme and target Indonesia (2021) | Implemented | yes | yes | 2021 | 2050 |
| 10a-IDN-GEN-TAX-60 | 220205896 | Economy-wide | Market-based instruments, GHG emission reduction crediting and offsetting mechanism, Fiscal or financial incentives, $CO_2$ taxes | Fiscal or financial incentives, Strategic planning | Energy service demand reduction and resource efficiency | New Carbon Law Indonesia (2021) | Implemented | yes | yes | 2021 | 2060 |
| 11a-IDN-GEN-FGAS-45 | 230706185 | Economy-wide | Kigali Amendment on HFCs | Target, GHG reduction target | Energy service demand reduction and resource efficiency, non-energy use | Kigali Amendment on HFCs Indonesia (2021) | Implemented | yes | yes | 2021 | 2045 |

**Table 16**
Climate policy modelling protocol for South Africa

| South Africa | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0a-SAF-GEN-NDC-25 | 211205573 | Economy-wide | NDC Emission reduction target | GHG reduction target, Political & non-binding GHG reduction target | Energy efficiency, Energy service demand reduction and resource efficiency, non- | Nationally Determined Contribution - NDC South Africa (2021) | Planned | yes | no | 2021 | 2030 |

| South Africa | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | energy use, Other low-carbon technologies and fuel switch, Renewables | | | | | | |
| 0b-SAF-GEN-NDC-30 | 211205573 | Economy-wide | NDC Emission reduction target | GHG reduction target, Political & non-binding GHG reduction target | Energy efficiency, Energy service demand reduction and resource efficiency, non-energy use, Other low-carbon technologies and fuel switch, Renewables | Nationally Determined Contribution - NDC South Africa (2021) | Planned | yes | no | 2021 | 2030 |
| 0c-SAF-GEN-LTS-50 | 230806226 | Economy-wide | LTS Emission reduction target | $CO_2$ reduction target, Political & non-binding $CO_2$ reduction target | Energy efficiency, Energy service demand reduction and resource efficiency, non-energy use, Other low-carbon technologies and fuel switch, Renewables | Net zero targets \| Climate Action Tracker | Planned | yes | no | 2022 | 2050 |
| 1a-SAF-ENE-REN-30 | 211001524 | Electricity and heat | Renewable Capacity Target (Integrated Energy Plan / Integrated Resource Plan for Electricity) | Strategic planning, Regulatory Instruments, Renewable energy target, Political & non-binding renewable energy target | Renewables, Energy efficiency | Integrated Resource Plan South Africa (2019) | Implemented | yes | yes | 2020 | 2030 |
| 1b-SAF-ENE-REN-30 | 211001524 | Electricity and heat | Renewable Capacity Target (Integrated Energy Plan / Integrated Resource Plan for Electricity) | Strategic planning, Regulatory Instruments, Renewable energy target, Political & non-binding renewable energy target | Renewables, Energy efficiency | Integrated Resource Plan South Africa (2019) | Implemented | yes | *yes* | 2020 | 2030 |

| South Africa | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1c-SAF-ENE-REN-30 | 211001524 | Electricity and heat | Renewable Capacity Target (Integrated Energy Plan / Integrated Resource Plan for Electricity) | Strategic planning, Regulatory Instruments, Renewable energy target, Political & non-binding renewable energy target | Renewables, Energy efficiency | Integrated Resource Plan South Africa (2019) | Implemented | yes | yes | 2020 | 2030 |
| 1d-SAF-ENE-REN-30 | 211001524 | Electricity and heat | Renewable Capacity Target (Integrated Energy Plan / Integrated Resource Plan for Electricity) | Strategic planning, Regulatory Instruments, Renewable energy target, Political & non-binding renewable energy target | Renewables, Energy efficiency | Integrated Resource Plan South Africa (2019) | Implemented | yes | yes | 2020 | 2030 |
| 1e-SAF-ENE-REN-30 | 211001524 | Electricity and heat | Renewable Capacity Target (Integrated Energy Plan / Integrated Resource Plan for Electricity) | Strategic planning, Regulatory Instruments, Renewable energy target, Political & non-binding renewable energy target | Renewables, Energy efficiency | Integrated Resource Plan South Africa (2019) | Implemented | yes | yes | 2020 | 2030 |
| 1f-SAF-ENE-REN-30 | 211001524 | Electricity and heat | Renewable Capacity Target (Integrated Energy Plan / Integrated Resource Plan for Electricity) | Strategic planning, Regulatory Instruments, Renewable energy target, Political & non-binding renewable energy target | Renewables, Energy efficiency | Integrated Resource Plan South Africa (2019) | Implemented | yes | yes | 2020 | 2030 |
| 1g-SAF-ENE-CPO-30 | 211001524 | Electricity and heat | Integrated Resource Plan for Electricity / Reduce Reliance on Coal | Strategic planning, Regulatory Instruments, Renewable energy target, Political & non-binding renewable energy target | Renewables, Energy efficiency | Integrated Resource Plan South Africa (2019) | Implemented | yes | no | 2020 | 2030 |

| South Africa | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2a-SAF-ENE-FIN-11 | 211002614 | Electricity and heat | Renewable Energy Independent Power Producer Programme (REIPPP) | Economic instruments, Tendering schemes, Market-based instruments, Policy support | Renewables | Renewable Energy Independent Power Producer Programme (REIPPP) South Africa (2011) | Implemented | | no | 2011 | |
| 3a-SAF-BUI-EFF-30 | 211001956 | Buildings | National Development Plan / zero emission building standards | Strategic planning, Target | Energy efficiency | National Development Plan South Africa (2012) | Implemented | | no | 2012 | 2030 |
| 4a-SAF-TRA-BIO-15 | 211005310 | Transport | Regulations Regarding the Mandatory Blending of Biofuels with Petrol and Diesel / Biofuels Industrial Strategy | Tax relief, Renewable energy target | Renewables | Biofuels Industrial Strategy South Africa (2007) | Implemented | yes | yes | 2007 | |
| 4b-SAF-TRA-BIO-15 | 211005310 | Transport | Regulations Regarding the Mandatory Blending of Biofuels with Petrol and Diesel / Biofuels Industrial Strategy | Tax relief, Renewable energy target | Renewables | Biofuels Industrial Strategy South Africa (2007) | Implemented | yes | yes | 2007 | |
| 5a-SAF-BUI-EFF-11 | 211001920 | Buildings | Building codes / National Building Regulation 2011 | Building codes and standards | Energy efficiency | National Building Regulation South Africa (2011) | Implemented | | no | 2011 | |

| South Africa | Policy database ID | Sector name | Policy target/policy instrument | Type of policy instrument | Policy type | Name of policy (+ link to Climate Policy database) | Implementation state | Quantifiable | IMAGE CurPol scenario inclusion | Start date of implementation | End date of implementation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6a-SAF-GEN-TAX-25 | 211000400 | Economy-wide | Carbon tax | $CO_2$ taxes, Economic instruments, Fiscal or financial incentives | Energy service demand reduction and resource efficiency, Energy efficiency, Renewables, Other low-carbon technologies and fuel switch, non-energy use | Carbon Tax South Africa (2019) | Implemented | yes | yes | 2019 | 2025 |
| 7a-SAF-TRA-MOD-35 | 211000349 | Transport | Bus Rapid Transport in Cape Town | Strategic planning | Energy service demand reduction and resource efficiency, non-energy use | Bus Rapid Transit Systems (BRT) South Africa (2014) | Implemented | | *no* | 2014 | |
| 9a-SAF-ENE-EFF-30 | 211001972 | Electricity and heat | National Energy Efficiency Strategy | Energy efficiency target | Energy efficiency | National Energy Efficiency Strategy Post 2015 South Africa (2016) | Implemented | | no | 2016 | |
| 10a-SAF-GEN-FGAS-45 | 220205869 | Economy-wide | Kigali Amendment on HFCs | Target, GHG reduction target | Energy service demand reduction and resource efficiency, non-energy use | Kigali Amendment on HFCs \| Climate Policy Database / https://ozone.unep.org/sites/default/files/2020-01/FAQs_Kigali_Amendment.pdf | Implemented | yes | yes | 2021 | 2045 |