

Synthesis of

# Long-term Strategies for Decarbonization



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## Authors Organized by Chapters

### Executive Summary

- **Authors:** Subash Dhar<sup>1</sup>, Leona Harting<sup>7</sup>, Fatemeh Bakhtiari<sup>1</sup>, Clara Lepin<sup>5</sup>, Yann Briand<sup>5</sup>, Henri Waisman<sup>5</sup>, Vicente Guazzini<sup>5</sup>, Lauren Harry-Villain<sup>5</sup>, and Talat Munshi<sup>1</sup>
- **Reviewers:** Anne Olhoff<sup>1</sup>

### Chapter 1: Introduction

- **Authors:** Subash Dhar<sup>1</sup>
- **Reviewers:** Anne Olhoff<sup>1</sup>

### Chapter 2: A Review of Long-term Low-Emission Development Strategies (LT-LEDS) at the National Level

- **Authors:** Leona Harting<sup>7</sup>, and Fatemeh Bakhtiari<sup>1</sup>
- **Reviewers:** Sudhir Sharma<sup>2</sup>, Viktoria Dimitrova<sup>3</sup>, Shivika Mittal<sup>4</sup>, Myung Lee<sup>1</sup>, Darshini Mahadevia<sup>6</sup>, Henri Waisman<sup>5</sup>, Clara Lepin<sup>5</sup>, and Vicente Guazzini<sup>5</sup>

### Chapter 3: National Pathways to Net Zero: Key Characteristics and Policy Insights

- **Coordinating Authors:** Clara Lepin<sup>5</sup>, Yann Briand<sup>5</sup>, Henri Waisman<sup>5</sup>, Vicente Guazzini<sup>5</sup>, and Lauren Harry-Villain<sup>5</sup>
- **Contributing Authors:** See table at the end of the acknowledgement.
- **Reviewers:** Sudhir Sharma<sup>2</sup>, Viktoria Dimitrova<sup>3</sup>, Shivika Mittal<sup>4</sup>, Myung Lee<sup>1</sup>, Darshini Mahadevia<sup>6</sup>, and Balakrishna Pisupati<sup>5</sup>

### Chapter 4: A Review of Net-Zero Assessments at a Sectoral Level: Delivering Fossil-Fuel Phase-Out from the Power Sector

- **Authors:** Subash Dhar<sup>1</sup>
- **Reviewers:** Sudhir Sharma<sup>2</sup>, Myung Lee<sup>1</sup>, and Dipti Gupta<sup>8</sup>

### Chapter 5: A Review of City-Level Net-Zero Plans

- **Authors:** Talat Munshi<sup>1</sup> and Subash Dhar<sup>1</sup>
- **Reviewers:** Utkarsh Patel<sup>9</sup>, Sudhir Sharma<sup>2</sup>, and Darshini Mahadevia<sup>6</sup>

1. UNEP CCC
2. UNEP
3. 2050 Pathways
4. CICERO
5. Deep Decarbonization Pathways initiative, IDDRI, Sciences Po Paris
6. Ahmedabad University
7. Independent Consultant
8. IIM Lucknow
9. Centre for Social and Economic Progress

**Contributing authors of Chapter 3:** « National pathways to net zero: Key characteristics and policy insights »

<b>Argentina</b>	Francisco Lallana (Fundacion Bariloche), Marina Recalde (Fundacion Bariloche / CONICET), Aliosha Behnisch (Fundacion Bariloche / CONICET), Leonidas Osvaldo Girardin (Fundacion Bariloche / CONICET), Gustavo Nadal (Fundacion Bariloche), Ignacio Sagardoy (Fundacion Bariloche), Gonzalo Bravo (Fundacion Bariloche), Nicolás Di Sbroiavacca (Fundacion Bariloche)
<b>Brazil</b>	Emilio Lebre La Rovere, Marcio de Almeida D'Agosto, Carolina Burle Schmidt Dubeux, Saulo Machado Loureiro, William Wills, Michele Cotta Walter, Pedro Ninô de Carvalho, Daniel Neves Schmitz, George Vasconcelos Goes, Bruna Silveira Guimarães, Erika Carvalho Nogueira, Lisandra Gomes Mateus (Federal University of Rio de Janeiro)
<b>Canada</b>	Chris Bataille (IDDRI/NetZeroIndustry.org), Seton Stiebert (International Institute for Sustainable Development (ISSD)/NetZeroIndustry.org), Francis Li (NetZeroIndustry.org)
<b>China</b>	Fei Teng, Jun Xie, Qiang Liu, Xin Su, Xu Deng (Tsinghua University)
<b>Costa Rica</b>	Jessica Roccard, Karla Hernandez, Luis Victor-Gallardo, Angelica Madrigal, Jairo Quiros-Tortos (Climate Lead Group)
<b>Dominican Republic</b>	Jairo Quiros-Tortos, Angelica Madrigal, Luis Victor-Gallardo (Climate Lead Group)
<b>France</b>	Michel Colombier (IDDRI)
<b>European Union</b>	Antoine Oger (Institute for European Environmental Policy (IEEP))
<b>Germany</b>	Charlotte Senkpiel (Fraunhofer-Institute for Solar Energy Systems (ISE)), Hans-Martin Henning (Fraunhofer-Institute for Solar Energy Systems (ISE)), Barbara Schlomann (Fraunhofer Institute for Systems and Innovation Research (ISI)), Brigitte Knopf (Institute for Social Climate Policy), Nicolai Hans (Expertenrat für Klimafragen (ERK)), Cynthia Schmitt (Expertenrat für Klimafragen (ERK))
<b>Guatemala</b>	Jam Angulo, Angelica Madrigal, Jairo Quiros-Tortos (Climate Lead Group)
<b>India</b>	Amit Garg, Saritha Sudharmma Vishwanathan, Vidhee Avashia, Jyoti Maheshwari (Indian Institute of Management Ahmedabad)
<b>Indonesia</b>	Rizaldi Boer (Institut Pertanian Bogor), Retno Gelang Dewi (Institut Teknologi Bandung), Ucok Siagian (Institut Teknologi Bandung), Lukytawati Anggraeni (Institut Pertanian Bogor)
<b>Côte d'Ivoire</b>	Sylvestre Kouassi, Pascal N'Zue, Soro Yalamoussa Brahim, Kouman Donald, Simplicie Yao (University Alassane-Ouattara - UAO)
<b>Japan</b>	Mikiko Kainuma (Institute for Global Environmental Strategies – IGES), Tomoko Ishikawa (Institute for Global Environmental Strategies – IGES), Go Hibino (National Institute for Environmental Studies – NIES), Toshihiko Masui (National Institute for Environmental Studies – NIES)
<b>Kazakhstan</b>	George Safonov (IDDRI, DEXAlliance)
<b>Mexico</b>	Daniel Buira, Jordi Tovilla, Thalia Hernandez (Tempus Analitica)
<b>Nigeria</b>	Chukwumerije Okereke, Ogheneruona Diemuodeke, Cosmas Anyanwu, Chukwuemeka Emekwe, Nnaemeka Emodi, Uchenna Nnamani, Kesiena Owebor, Chinedum Nwachukwu, Onyekwere Ojike (Centre for Climate Change and Development, Alex-Ekwueme Federal University Ndufu-Alike)

<b>Senegal</b>	Samba Fall, Dr Ansoumata Noumou Djite, Cheikh Abdou Khadre Dieylani Diop, Ndeye Maimouna Ba, Ndeye Martinia Gomis (ENDA Energie)
<b>South Africa</b>	Harro Von Blottnitz, Andrew Marquard, Jesse Burton, Bryce Mc Call, Julia Tatham (University of Cape Town)
<b>Thailand</b>	Jakapong Pongthanasawan, Phimsupha Kokchang (Energy Research Institute, Chulalongkorn University)
<b>United States</b>	Alicia Zhao, Christoph Bertram, Claire Squire, Kiara Ordonez Olazabal, Laura Hinkle, Nate Hultman, Ryna Cui (Center for Global Sustainability, University of Maryland)

**Editors:** Subash Dhar

**Coordination:** Subash Dhar

**Communications:** Mette Annelie Rasmussen, Lasse Hemmingsen and Aristedis Tsakiris (UNEP\_CCC)

**Design, layout and language editing:** Formato Verde

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# Executive Summary

In this publication, we review the literature on long-term decarbonization strategies at three levels – national, sectoral, and city. At the national level, we examine the literature on long-term low-emission development strategies (LT-LEDS) submitted to the United Nations Framework Convention on Climate Change (UNFCCC), as well as long-term decarbonization strategies prepared under the Deep Decarbonization Pathways Project, through which over 20 countries have submitted their decarbonization pathways. At the sectoral level, we analyse the power sector, as electrification across end uses—including transport, industry, households, and services—emerges as the key lever for decarbonization. Finally, we consider urban areas, which account for over 70 per cent of global greenhouse gas emissions, and where many cities have announced their own decarbonization pathways for achieving net zero. This Executive Summary presents the key messages from the four chapters and concludes with four cross-cutting themes.

## Chapter 2.

**Long-term low-emission development strategies (LT-LEDS) are moving from vision statements to governance tools.**

Long-term low-emission development strategies (LT-LEDS) are rapidly evolving from high-level international submissions into central governance instruments that articulate national decarbonization visions and guide near-term implementation. Established under Article 4.19 of the Paris Agreement, LT-LEDS provide the systemic roadmaps required to achieve net-zero emissions by mid-century. With LT-LEDS now covering approximately three-quarters of global greenhouse gas emissions, countries are transitioning beyond headline targets towards comprehensive, economy-wide frameworks that embed climate ambition directly into core development priorities.

## **The need to include adaptation strategies, Short-Lived Climate Pollutants (SLCPs)**

However, critical gaps remain within these frameworks. While most strategies comprehensively address economy-wide CO<sub>2</sub> emissions, the integration of adaptation strategies and the treatment of Short-Lived Climate Pollutants (SLCPs),

specifically methane, remain insufficient. Addressing SLCPs is vital to slowing near-term warming and avoiding technology lock-in. Furthermore, to maintain credibility, modern LT-LEDS must evolve beyond static scenario modelling to function as ‘living frameworks.’ These frameworks require iterative review cycles, explicit investment roadmaps, and robust monitoring and reporting (M&R) mechanisms tailored to distinct socio-economic contexts. Ultimately, the effectiveness of LT-LEDS hinges less on ambitious end-century targets and more on the legal and institutional arrangements that embed these strategies within national budgeting, public policy, and a ‘whole-of-society’ implementation model.

## Chapter 3.

**National net-zero pathways require integrated, comprehensive policy packages rather than isolated interventions.**

LT-LEDS are instrumental in informing these packages by articulating short-term and long-term perspectives and by exploring the interactions between climate and socio-economic dimensions. Policy packages must trigger immediate emissions reductions by supporting the deployment of low-carbon solutions in sectors where they are already commercially viable, such as power generation, passenger transport, and the land-use sector. Simultaneously, policy packages must actively address structural inertias to avoid future carbon lock-in and prepare for the emergence of new technologies and infrastructure deployment compatible with longer term emission reductions and net zero. Crucially, these policy packages must also address the socio-economic challenges of the transition, guarding against price shocks that undermine the affordability of essential services and supporting the structural changes required in the industrial system.

**National net-zero pathways require a country-driven relentless decrease in the direct use of fossil fuels, maximization of carbon sinks in land use and forestry and a renewed approach to international cooperation.**

Although national pathways to net zero vary significantly according to socio-economic contexts, domestic energy landscapes, and national carbon-neutrality target dates,

they share common transition requirements. The first requirement is a steady reduction in fossil-fuel use, as the role of carbon capture and storage (CCS) is expected to remain limited due to technical and economic constraints. This transition away from fossil fuel can be compatible with socio-economic development under specific conditions: widespread electrification of end uses combined with the near-total phase-out of fossil fuels in power generation. It also requires proactive action on organizations, Behaviours, and infrastructure to decouple development from energy demand. Another key requirement is the expansion of net-negative carbon sinks in the land-use and forestry sectors through country-specific approaches that preserve other key functions of these sectors, such as food security, rural employment, resilience, and biodiversity. Finally, the realization of national transitions is deeply contingent upon a renewed approach to international cooperation across finance, technology transfer, and trade that places the needs and priorities of countries, as outlined in their national strategies, at its centre.

#### **Chapter 4.**

##### **Power sector decarbonization is the foundation of net zero.**

The electrification of end-use sectors means that rapid decarbonization of the power sector is the foundational lever for achieving net zero. A review of 11 national power sector strategies reveals three universal systemic priorities: establishing renewable energy as the backbone of electricity generation, using energy storage of varying durations to provide critical system flexibility, and strategically retaining or expanding nuclear energy, including Small Modular Reactors (SMRs), as a zero-carbon baseload asset. In addition, the anticipated production of green hydrogen and Power-to-X fuels is projected to significantly increase overall electricity demand.

##### **Power systems must become both low-carbon and climate-resilient**

However, the realization of these technical pathways is vulnerable to climate-induced hazards, such as extreme temperatures and prolonged droughts, which can simultaneously suppress generation capacity and increase demand. Methodologically, countries Analyse these uncertainties using scenario-rich modelling to quantify

energy flows or target-based roadmaps that outline specific phase-out years. Encouragingly, current short-term plans align closely with long-term LT-LEDS, focusing on the deployment of mature renewable technologies and the rapid enhancement of transmission grid capacity to guarantee system reliability as fossil fuels are phased out.

#### **Chapter 5.**

##### **Cities are critical for achieving net-zero**

While national strategies set macro-level trajectories, achieving net zero depends heavily on urban centres. Although cities occupy less than two per cent of the Earth's land area, they house 56 per cent of the global population, consume 78 per cent of global energy, and are responsible for the majority of global greenhouse gas emissions. A critical tension exists between the technically feasible decarbonization solutions identified through advanced modelling and the actual jurisdictional, technical, and financial capacities of municipal governments to implement them. While city administrations exercise direct control over Scope 1 and 2 emissions (stationary energy, waste management, and transport), tackling embedded Scope 3 emissions generated beyond city boundaries remains a complex governance challenge.

##### **Unlocking net-zero strategies at the city level requires a paradigm shift in financing**

A distinguishing feature of modern urban assessments is the integration of adaptation into the mitigation framework. In the Global South in particular, immediate physical vulnerabilities to heatwaves and flooding necessitate adaptive measures, such as substantial increases in cooling demand, that pose significant, countervailing mitigation challenges. Furthermore, urban net-zero strategies are rarely driven by abstract temperature targets; rather, air quality improvement and the creation of green economies are the primary drivers of action.

Unlocking deep urban decarbonization requires a paradigm shift in public finance. City governments must view net-zero strategies not merely as unrecoverable capital expenditures, but as necessary investments that deliver substantial operational savings over their lifetime. Public finance mechanisms must focus on de-risking private investment and creating enabling environments that steer inevitable municipal spending towards low-carbon infrastructure.

## Cross-cutting messages from nations to cities

Four overarching messages emerge from the review at national, sectoral, and city scales.

### Theme 1.

#### Multi-level governance

A dominant theme running throughout the text is the evolution of climate strategy from long-range emissions targets to deeply embedded, institutional governance. In Chapter 2, this theme is articulated through the maturation of LT-LEDS. The credibility of LT-LEDS no longer stems merely from their submission under the Paris Agreement, but from their practical function as “living frameworks” characterized by clear investment roadmaps and monitoring and reporting. The assertion that effective delivery relies entirely on “institutional arrangements,” “national governance frameworks,” and a “whole-of-society” approach reinforces this institutional imperative.

This macro-level governance mandate is mirrored at the city level in Chapter 5. A sophisticated technological mapping of deep decarbonization pathways is of limited value if a municipal government lacks the underlying “capacity and mandate to raise resources independently”. Thus, across all scales of administration the success depends entirely on building robust, multi-level governance architectures capable of translating long-term visions into near-term policy processes, legal mandates, and investable project pipelines.

### Theme 2.

#### The inseparability of mitigation and adaptation

Historically, global climate policy has treated mitigation and adaptation as parallel, largely non-overlapping disciplines. Across multiple chapters, the text demonstrates that mitigation and adaptation are now structurally inseparable and often stand in direct tension with one another.

Chapter 2 flags a “significant gap” in the integration of adaptation into national LT-LEDS frameworks. The subsequent chapters explain why this planning gap is so systemically dangerous. Chapter 3 establishes that “significant electrification needs across most end uses” are the primary lever for global decarbonization. However, Chapter 4 reveals that power systems are increasingly vulnerable to climate hazards such as extreme temperatures,

droughts, and wind speeds, which can simultaneously suppress supply and spike demand. Chapter 5 brings this challenge into the urban context. For example, as cities face deadly heatwaves, the adaptive measures required (such as significant increases in cooling demand) “would significantly increase electricity demand”.

### Theme 3.

#### Socio-economic viability as the core enabler

Deep decarbonization cannot be achieved through a purely emissions-focused lens. To overcome the immense political and social challenges inherent in such a transition, decarbonization pathways must be intrinsically linked to immediate socio-economic co-benefits, principally energy affordability, improved air quality, industrial modernization, and robust green job creation. If the transition threatens basic socio-economic security, it will fail to secure the necessary ownership by a diversity of national stakeholders.

Chapter 3 explicitly states that policy packages must be designed to manage the socio-economic challenges of the transition, particularly those driven by price increases that can undermine the affordability of essential services. It calls for aligning climate action with broad “industrial transitions” and accompanying “structural shifts in economic systems” to provide the goods, technologies, and services required for a new low-carbon economy.

This top-down, national economic mandate intersects with the bottom-up drivers identified at the municipal level in Chapter 5. For cities, particularly those in the Global South, abstract global temperature targets are secondary priorities. Instead, the text reveals that “air quality is the primary driver of climate action,” and the concept of net zero is viewed fundamentally as an “economic recovery strategy for creating a green economy and green jobs”. Furthermore, Chapter 5’s emphasis on steering inevitable spending into low-carbon options to “capture savings to repay capital” reinforces the importance of framing the transition in terms of long-term economic logic and affordability.

### Theme 4.

#### Spatial interdependency

The overarching message concerns the complex spatial interdependencies required to achieve net zero. Chapter 5 notes that while cities control direct emissions, they also encompass substantial “Scope 3 emissions” embedded in

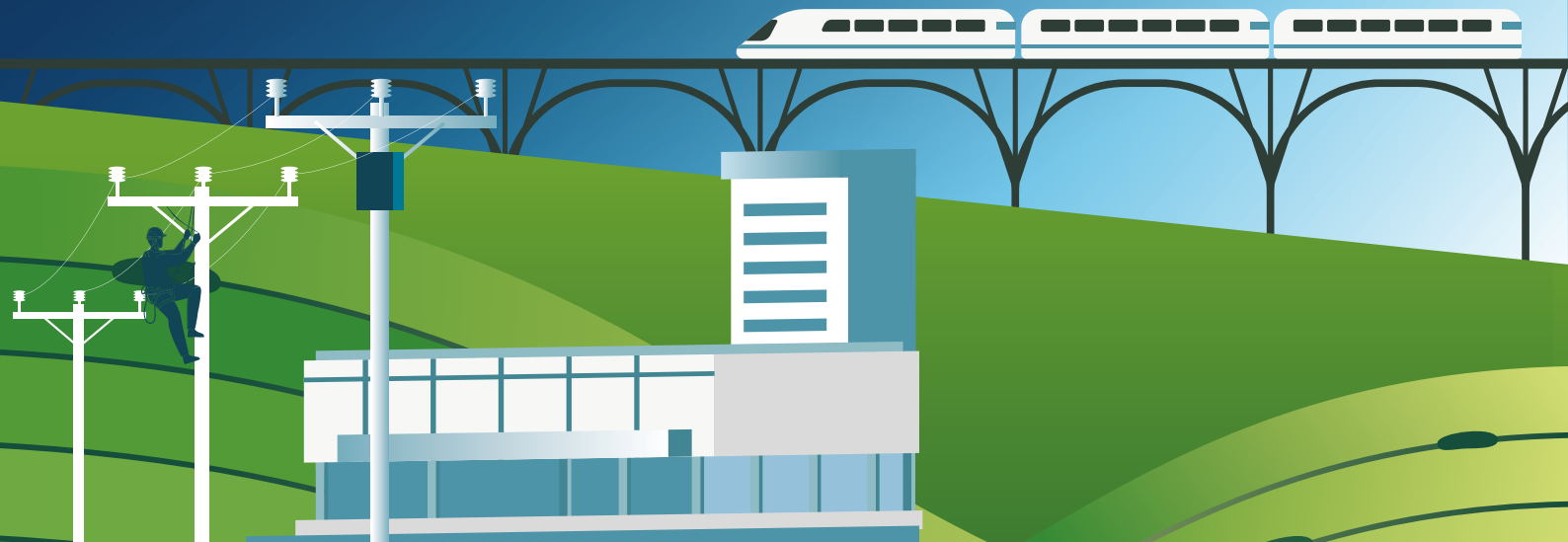
goods, food, and materials consumed by urban residents but produced far beyond city boundaries. This implies that cities cannot decarbonize in isolation; their success depends on broader national and regional systems.

Similarly, in Chapter 4, as regional grids increasingly rely on geographically dependent renewable resources, “enhancing grid and transmission capacity is essential for linking demand to supply” across vast distances. Furthermore, Chapter 4 highlights deep geopolitical interdependencies, noting that “electricity imports are considered essential for fostering regional cooperation”, while also acknowledging that “fuel imports for electricity generation... are seen as an energy security risk”.

Finally, Chapter 3 elevates this spatial challenge to the global level, concluding that national strategies are heavily reliant on “internationally driven enablers” and require new multilateral approaches to “finance, technology, and trade”. The overarching message is clear: deep decarbonization is a profound spatial challenge. Localized urban demand centres require extensive and flexible transmission infrastructure to deliver electrified services, which in turn depends on cross-border grid cooperation, secure international supply chains, and technology flows. Isolated, localized climate planning is therefore insufficient.

# 1.

## Introduction



Alongside Nationally Determined Contributions (NDCs), long-term low-emission development strategies (LT-LEDS) form the backbone of the Paris Agreement and pave the way for low-emission development pathways around the globe. Their coherence and mutual alignment are therefore critical to ensuring ambitious and effective action towards limiting the increase in global average temperature and adapting to the impacts of climate change. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) is unambiguous about the need for immediate action and achieving net zero CO<sub>2</sub> emissions by 2050, though due to delayed action, it is clear that global warming is expected to exceed 1.5 °C in the coming decade and 1.5 °C can be seen more as a long-term goal that can be achieved with an overshoot strategy, specifically, allowing temperatures to exceed 1.5 °C and then being brought back down by using net-negative emissions in the second half of the century.

There is no one-size-fits-all format for LT-LEDS, and their scope and depth are determined by the countries themselves. However, because these strategies provide a pathway for whole-of-society transformation and serve as a vehicle to achieve the long-term goals of the Paris Agreement,

they should include common elements: intermediate and long-term targets, a clear roadmap for implementation, investment plans, and robust reporting and review mechanisms. In addition, the successful delivery of NDC and LT-LEDS targets requires their integration into national development priorities, sectoral planning, and downscaling to subnational level to ensure action is taken closer to where implementation happens and impacts are felt.

To inform policymakers, think tanks, and researchers about the current status and best practices, this publication reviews publicly available literature on long-term net-zero strategies at three levels: national, sectoral, and city. At the national level, the literature covers LT-LEDS (Chapter 2) submitted to the UNFCCC, as well as strategies prepared under the Deep Decarbonization Pathways Project (Chapter 3), which presents detailed decarbonization pathways for 21 countries. At the sectoral level, the power sector is analyzed (Chapter 4), as the electrification of end uses (transport, industry, households, services) emerges as the primary lever for decarbonization. Finally, at the city level, the publication examines urban net-zero strategies (Chapter 5) developed by municipal governments to achieve net zero.

# 2.

## A Review of Long-Term Low-Emission Development Strategies (LT-LEDS) at the National Level



### 2.1 Introduction. Aligning LT-LEDS and net zero

According to the IPCC's Sixth Assessment, keeping global warming within 1.5 °C requires global carbon dioxide emissions to reach net zero by 2050, followed by net-zero targets for all remaining greenhouse gas (GHG) emissions. However, due to delayed action, global warming is expected to exceed 1.5 °C in the coming decade and 1.5 °C can be seen more as a long-term goal that can be achieved with an overshoot strategy, specifically allowing temperatures to exceed 1.5 °C and then being brought back down by using net-negative emissions in the second half of the century. Yet while this scientific imperative is clear, the institutional and governance mechanisms required to translate it into credible national actions remain poorly understood and unevenly implemented. This is a sobering reminder of the importance of developing long-term strategies and strengthening already developed strategies (IPCC 2023). At the same time, long-term low-emission development strategies (LT-LEDS) themselves can function as core governance frameworks:

they create a common long-term vision, provide an anchor for coordinating diverse actors and agendas, and give concrete direction for the design of near-term policies and investments. Building on this bidirectional relationship, this chapter examines how effective governance and institutional arrangements both enable credible LT-LEDS and, conversely, how well-designed LT-LEDS can strengthen the overall governance of national climate action by creating a common anchor for mobilizing a diverse range of actors and providing concrete directions for policy design and implementation on pathways to net zero (Denegri, 2025; WRI n.d.).

The invitation to prepare LT-LEDS is formally anchored in the international legal framework through Article 4, paragraph 19, of the Paris Agreement, which invites all Parties to formulate and communicate long-term low greenhouse gas emission development strategies (UNFCCC 2015). While many countries have communicated long-term visions

to the United Nations Framework Convention on Climate Change (UNFCCC), a significant challenge remains in bridging the gap between these international submissions and their effective integration into national policymaking. This challenge often stems from limitations in technical and institutional capacities required to develop comprehensive long-term strategies that can operationalize net-zero targets. Observed across a range of development contexts, these limitations can result in strategies that lack sufficient detail on sectoral implementation pathways, transparency, concrete timelines, and investment requirements. As a result, many countries announce a target year for net zero, but the baseline data, specific pathways, decision points, and peaking years often remain undefined, weakening the credibility and usefulness of these strategies for decision-making. Where appropriately mandated and embedded in domestic decision-making processes, LT-LEDS can therefore serve as a central ‘coordination device’ that links long-term vision, medium-term targets, and near-term implementation choices across government and with non-state actors.

Throughout this chapter, the terms “long-term low-emission development strategies (LT-LEDS)” and “long-term low greenhouse gas emission development strategies” are used to refer specifically to the instruments invited under Article 4.19 of the Paris Agreement. In contrast, the term “long-term strategies (LTS)” is used in a broader sense, and may also encompass national long-term climate strategies that are not formally submitted under Article 4.19 or are primarily intended for domestic use. The term “net zero” is used to describe an emission reduction objective that many LT-LEDS and LTS are designed to achieve, rather than as a separate strategy type.

Long-term strategies are essential for achieving net-zero GHG emissions, limiting warming, and preventing some of the worst impacts of climate change (UNFCCC Secretariat, 2023). National LT-LEDS are important for countries because they provide a vision of a net-zero future and outline sectoral pathways needed to achieve it, while guiding near-term climate plans, actions, and policies. To provide the necessary clarity, a robust LT-LEDS should include a clear baseline, current policy scenarios, and net-zero scenarios that consider the national socio-economic and environmental circumstances, emerging technologies, and critical considerations of equity and fairness. LT-LEDS support a better understanding of how countries are advancing the transition to decarbonization, carbon neutrality, and ultimately to net zero (Tan et al., 2022). These strategies can be used by countries to set long-term climate

and development goals and guide the short-term decisions needed to achieve net-zero emissions and climate resilience (WRI n.d.). Thus, robust long-term decarbonization strategies—those characterized by technically feasible pathways and resilient policy frameworks—should include analysis of multiple net-zero futures. These strategies must be based on scenario modelling that accounts for various socio-economic variables to identify the most achievable and least risky pathways to climate neutrality. On this basis, governments and policymakers can decide on the most appropriate pathway to follow and begin preparing for it today. For LT-LEDS to provide net-zero pathways and actionable information for near-term decision-making, relevant decision points need to be considered and time frames required to implement climate actions and measures, including when key technologies, infrastructures, and Behavioural changes need to be in place (Velten et al., 2022).

The Paris Agreement invites all parties under the UNFCCC to formulate and communicate long-term low greenhouse gas emission development strategies, considering their common but differentiated responsibilities and capabilities, in the light of national circumstances (UNFCCC, 2015). LT-LEDS are important for countries because they help pave the way for system-wide transformation to reduce the risk of missing opportunities for faster and stronger climate action. For example, a long-term perspective can clarify the sequencing needed to deliver large-scale transformations on time while balancing the costs and benefits. In the transport sector, this could include indicating the share of electric buses and electric vehicles that need to enter the market over time, as well as the pace required for charging infrastructure deployment and associated energy demand. As such, LT-LEDS provide a whole-of-society transformation roadmap, which is essential for achieving net-zero targets by mid-century, in line with the latest IPCC global warming estimations (IPCC, 2023; United Nations Environment Programme, 2025). By December 2025, 80 parties, representing nearly 75 per cent of global GHG emissions, had submitted their LT-LEDS to the UNFCCC (UNFCCC, 2026). The most recent submissions were from Czechia, Togo, Jamaica, and Equatorial Guinea (Climate Watch Data, n.d.).

LT-LEDS support a just transition, prepare countries for risks and uncertainties, encourage investment, inform NDC development, identify technological needs and gaps, and provide opportunities to include a cross-sectoral perspective (Vener et al., 2019). Consequently, LT-LEDS are important instruments for countries to pursue a transition towards

net-zero emissions, describing a state in which more carbon dioxide is captured than is emitted (WRI n.d.). Of the 80 LT-LEDS submitted to the UNFCCC that were analyzed, almost all include quantified targets for carbon neutrality or net-zero emissions, although target years range from around mid-century to 2070 and are not always explicitly framed as “net zero 2050” in the strategy text (UNFCCC, 2026; UNFCCC Secretariat, 2023).

The Republic of the Marshall Islands, for example, is committed to achieving net zero by 2050 at the latest (Marshall Islands, 2018; United Nations Environment Programme, 2025). The remainder of this chapter examines how institutional arrangements, governance mechanisms, and capacities shape the credibility, feasibility and implementation of these long-term targets, drawing on a structured review of LT-LEDS submitted to the UNFCCC.

## 2.2 Methodologies and scope of the LT-LEDS assessment

In this section, we outline the main dimensions and criteria used in our qualitative review of 80 LT-LEDS submitted to the UNFCCC. These dimensions also highlight the key features that robust, implementation-oriented LT-LEDS should ideally include. The assessment presented in this chapter draws on a comparative review of submitted LT-LEDS and synthesis reports prepared by the UNFCCC and UNEP (UNFCCC Secretariat, 2022, 2023; United Nations Environment Programme, 2025a). We assess the scope covered by the LT-LEDS of countries by examining the sectors covered, the temporal horizons of mitigation scenarios and their design (components), adaptation, gases covered, and Short-Lived Climate Pollutants (SLCPs), as well as institutional and governance dimensions. It is crucial for countries to incorporate sector-specific targets from the earliest stages of designing and implementing their LT-LEDS to achieve the defined goals in LT-LEDS (United Nations Environment Programme, 2025).

### 2.1.1 Sectoral and emissions coverage

Most LT-LEDS submitted to the UNFCCC cover economy-wide emissions, as specified in the IPCC reporting framework, and indicate that countries’ long-term mitigation goals cover all major sectors, typically including:

- **Energy** (power generation, fuel supply)
- **Transport** (road, aviation, and shipping)
- **Industry** (steel, cement, chemicals, and manufacturing)
- **AFOLU** (Agriculture, Forestry, and Other Land Use)
- **Buildings** (residential and commercial)
- **Waste**

However, sectoral pathways in LT-LEDS vary considerably across countries. Some strategies pursue economy-wide decarbonization pathways, while others focus on sector-specific or phased approaches, often combining sectoral targets with cross-sectoral measures. A few countries also indicate that their long-term mitigation goal covers emissions coming from international aviation, shipping, or both (United Nations Environment Programme, 2025).

### 2.1.2 Temporal horizons for mitigation

All submitted LT-LEDS to the UNFCCC communicate a long-term mitigation goal operationalized through the principle of Common But Differentiated Responsibilities and Respective Capabilities (CBDR-RC). This ensures that while the global vision is shared, the specific pace and nature of decarbonization roadmaps are tailored to each Party’s unique national circumstances and stage of development. The mitigation goals vary and are often described in different ways. In some cases, they are embedded in national legislation, while in others they remain aspirational or conditional on international support. Most LT-LEDS, particularly those with a stronger focus on mitigation measures, use multiple long-term scenarios, typically up to 2050, 2060, or 2070. The most widely communicated time frame for quantifiable long-term mitigation goals is 2050, which is identified in 87 per cent of LT-LEDS (68 out of 78 countries). In many cases, these time horizons align with the year in which the economy is expected to achieve net zero overall (Climate Watch Data, n.d.).

## Scenario design

All the scenario-based assessments in countries' LT-LEDS include a baseline or a reference scenario that is generally based on the continuation of current policies and without additional climate ambition. The mitigation scenarios are typically high-ambition decarbonization pathways and are often labelled net-zero, low-emission development pathways, or Paris-aligned scenarios. The scenarios provide useful information on emission trajectories, peaking years, sectoral transitions, and the role of CO<sub>2</sub> removals through CCS or any other means. They are also used by some countries to analyse policies and strategies, such as faster electrification, greater renewable energy uptake, delayed technology availability, and others. Typically, scenarios are analyzed using models. Commonly used model types include energy system models (bottom-up optimization or simulation models), integrated assessment models (IAMs), macroeconomic models, and computable general equilibrium (CGE) models. In some cases, countries complete model-based analyses with complementary methods such as stakeholder consultations, steering committees, and expert judgement. Overall, the methodologies adopted by countries depend on national capacity.

## Adaptation, resilience, and loss and damage

Parties primarily focus on mitigation measures in their LT-LEDS, although adaptation measures are also included qualitatively or in a less quantitative way, with a focus on climate resilience, nature-based solutions, and climate-resilient infrastructure. In some countries, adaptation-mitigation are analyzed together in certain sectors, for example, for forestry and agriculture. In others, synergies across terrestrial and coastal biodiversity and ecosystem sectors have been highlighted as important (UNFCCC Secretariat, 2022; United Nations Environment Programme, 2025). A smaller but growing number of LT-LEDS also address elements of economic and non-economic loss and damage (L&D). For instance, Thailand's LT-LEDS includes a comprehensive vulnerability analysis and a description of necessary adaptation measures, signaling an emerging recognition of climate impacts that go beyond traditional economic metrics (Thailand, 2022). However, mitigation considerations still dominate most strategies, and systematic integration of loss and damage—particularly non-economic loss and damage (NELD), such as impacts on ecosystems, culture, and livelihoods—remains limited. This limited integration of adaptation and loss and damage also reflects institutional fragmentation in many countries,

where mitigation and adaptation planning processes are often managed by different ministries or policy frameworks.

## 2.2.3 Gases covered and treatment of SLCPs

Most Parties use similar terminology to describe their long-term mitigation goals, but the scope and coverage of these goals sometimes differ. If we consider only countries that set a net-zero GHG emissions goal, which is broader for climate action than net-zero CO<sub>2</sub> emission, 58 per cent of countries (46 out of 80) describe long-term mitigation goals in terms of economy-wide net-zero GHG emissions (Climate Watch Data, n.d.; UNFCCC Secretariat, 2022).

The scope of LT-LEDS generally includes all major Kyoto gases. However, CO<sub>2</sub> dominates most pathways, and many countries still do not prioritize SLCPs—specifically methane (CH<sub>4</sub>), black carbon (BC), tropospheric ozone (O<sub>3</sub>), and hydrofluorocarbons (HFCs)—within their strategic frameworks. We argue that integrating SLCPs and associated air pollution mitigation measures may provide significant co-benefits and support more informed investment decisions. Prioritizing these pollutants offers a pathway to slow near-term warming, thereby providing the technical and political foundation to raise climate ambition in future NDC updates and future iterations of LT-LEDS (CCA, n.d.).

In our analysis, Mexico was identified as a best-case scenario, as it considered measures to reduce emissions of SLCPs. Mexico included a comprehensive strategy to address and reduce SLCPs including BC, CH<sub>4</sub>, and O<sub>3</sub>. For example, Mexico formulated a long-term vision goal to reduce emissions from SLCPs across different time frames by implementing cost-effective mitigation measures (Mexico, 2016, pp. 5, 53, 88). The assessment of Parties' overall inclusion of SLCP-related measures underlined that concrete action for a reduction in emissions in this area is still limited. Most countries stated the importance of reducing emissions of pollutants such as methane emissions, but did not implement concrete measures on how these reductions would be achieved. Additionally, integrating SLCPs as a component of the countries' LT-LEDS can prevent lock-in to high-carbon technologies and reduce losses associated with stranded assets. Therefore, scaled-up efforts across all sectors and for all gases are necessary to achieve the full potential of synergies and trade-offs in this new, emerging component of LT-LEDS implementation (United Nations Environment Programme, 2025).

### 2.2.4 Institutional and governance dimensions of the assessment

LT-LEDS are not just about greenhouse gas emissions. Beyond emissions trajectories, LT-LEDS also reflect the governance systems that shape how climate policy is coordinated, implemented, and monitored. They also encompass a wide range of social, economic, and environmental considerations, as well as help to identify and manage the risks and opportunities associated with the transition to a net-zero future. Effective strategies must also address the vertical integration of climate action; for example, regulatory frameworks can be used to link national efforts with subnational actions—such as the Paris Climate

Action Plan—ensuring that long-term national targets are effectively broken down into medium-term and short-term actions at the local level. In this chapter, our assessment therefore focuses specifically on the governance and institutional dimensions of LT-LEDS, along four key aspects: (i) the quality of the strategies, including their clarity, ambition, and internal consistency; (ii) the institutional arrangements and governance mechanisms for developing, implementing and revising the strategies; (iii) the integration of LT-LEDS into national and subnational development plans and policies; and (iv) the involvement of stakeholders, as well as the monitoring and evaluation of progress towards achieving LT-LEDS goals (2050 Pathways Platform, 2025; United Nations Environment Programme, 2025).

## 2.3 Capacities, governance mechanisms, and institutional arrangements for LT-LEDS

Even though LT-LEDS are not mandatory for Parties, their development and implementation are strongly encouraged for countries to have a guiding long-term roadmap and help develop NDCs that are aligned with LT-LEDS. There is no one-size-fits-all model for designing LT-LEDS, but there are key factors and elements that can strengthen their design and implementation. These include low-emission pathways, sustainable development considerations, mitigation and adaptation components, implementation approaches, sectoral strategies, plan monitoring, and revision processes. A core objective of this design is to ensure that LT-LEDS can actively guide national decisions by fostering high levels of ownership among key stakeholders and decision-makers (Abeysinghe, 2018; Denegri, 2025; WRI n.d.). Institutional arrangements supported by strong governance are needed to design and implement strategies effectively and ensure credibility and public acceptance, although they vary among countries and groups. Institutional arrangements assign clear roles, responsibilities, structures, incentives, and processes to manage and share information, as well as encourage stakeholder engagement (Bakhtiari et al., 2018). Bringing about systemic change requires the support of stakeholders, and LT-LEDS can provide a clear framework for evaluating policy options and national debates. They also act as an “ambition backstop” to remind stakeholders of the need for short-term actions for deep systemic change (Ross et al., 2021; United Nations Environment Programme, 2025).

In this chapter, “institutional capacities” refer to the ability of public institutions and their partners to coordinate, plan, implement, monitor, and revise LT-LEDS on a sustained basis. This includes political, organizational, human, and financial dimensions, as well as the formal and informal rules that shape climate-related decision-making (Bakhtiari et al., 2018).

A total of 82 per cent of LT-LEDS emphasized that institutional arrangements play a key role in planning, coordinating, and implementing climate change policy and action, while also supporting the integration of climate change considerations into broader development planning. Meanwhile, 11 per cent of LT-LEDS refer to institutional arrangements specifically established for their preparation and implementation measures. Of the LT-LEDS submitted to the UNFCCC, more than half mentioned high-level governance settings, meaning it is under the highest level of national government for long-term low-emission development planning and implementation. These are implemented through ad hoc interministerial body with a coordinating function. According to the LT-LEDS, such formal institutional arrangements serve multiple purposes, including raising awareness of climate change matters among relevant stakeholders such as governments, the private sector, non-governmental organizations, and civil society; ensuring the integration of climate and development priorities; providing high-level endorsement of the LT-LEDS to place climate change at the heart of government decision-making; outlining

an overarching vision for enhancing institutional capacities at all levels; preventing and minimizing possible challenges and trade-offs through coordination; ensuring effective coordination at the local, subnational, and national levels; and providing strategic orientation for achieving long-term goals. This can be done, for example, by periodically evaluating progress and aligning LT-LEDS updates with the NDC cycle to ensure that long-term goals remain transparent and actionable (UNFCCC Secretariat, 2022, 2023; United Nations Environment Programme, 2025). Crucially, while high-level governance settings provide the necessary political mandate for strategy design, there must be an explicit focus on ensuring governance continuity throughout implementation. Rather than treating the design phase as a standalone exercise, formal institutional arrangements should be structured to oversee and steer long-term implementation over several decades, ensuring that the strategic direction established during the drafting phase translates into sustained and effective action. This prevents the strategy from remaining a static document and instead establishes it as a living framework that bridges the gap between high-level vision and sectoral reality.

The presence of high-level political support, specifically defined as a formal mandate from the highest tier of government, such as the Office of the President, the Prime Minister, or a Cabinet-level climate council, is often the deciding factor in enabling a lead coordinating entity to effectively bring together various ministerial and non-governmental actors under a single governance structure. This “lead institute” acts as a hub to minimize transaction costs and enhance synergies across sectors.

Governance for LT-LEDS typically relies on three main coordination approaches:

- **Hierarchical coordination:** This includes both horizontal coordination across different ministries and vertical coordination between national and subnational levels of government.
- **Market-based coordination:** This involves the use of economic incentives, such as subsidies or tax deductions, to enhance the performance of various actors in achieving climate goals.
- **Network-based coordination:** This focuses on fostering shared knowledge, values, and strategies among partners, often involving negotiation and bargaining over emissions targets within specific sectors.

In practice, effective LT-LEDS governance usually combines three primary approaches: hierarchical, market-based, and network-based. To ensure that these strategies actively guide national decisions, it is critical to distinguish between governance mechanisms—the institutional arrangements and processes for decision-making—and the policy instruments used for implementation. For instance, a hierarchical approach may involve a climate framework law that provides the legal mandate and high-level endorsement necessary to place climate change at the heart of government decision-making. This structure then oversees the development and monitoring of market-based policy instruments, such as carbon pricing or green fiscal reforms. While these instruments are part of the policy package used to implement the strategy, governance itself resides in the clear allocation of roles and responsibilities for designing, regulating, and periodically evaluating these tools. Furthermore, network-based governance through multi-stakeholder platforms or climate assemblies ensures that the LT-LEDS remains a ‘living document’ with broad societal ownership. The relative weight of each approach varies according to national contexts, but the overarching goal is to maintain governance continuity, ensuring that the arrangements used to design the strategy remain robust enough to manage its long-term implementation and regular revision (Peters & Pierre, 2006; United Nations Environment Programme, 2025).

## 2.4 Institutional challenges of countries for designing and implementing LT-LEDS

Even though institutional arrangements are pivotal in making LT-LEDS more effective, the majority of countries analyzed indicated that they face certain financial, technical, and human challenges related to the coordination, stakeholder

engagement, sectoral integration, regulatory framework, human capacity, reporting, and international coordination of institutional capacities. These gaps can be categorized into two distinct phases: those relating to the elaboration (design) of the

strategy and those relating to the long-term implementation. The limited availability of financial, human, and technical resources is identified as one of the main reasons why developing countries include both conditional and unconditional scenarios on how to achieve their long-term goals in their LT-LEDS. In the design phase, a critical barrier is the historical institutional divide between climate and economic planning. LT-LEDS are, in essence, sustainable economic development plans, yet they have predominantly been spearheaded by Ministries of Environment, which often lack the expertise in macroeconomic planning traditionally held by economic planning departments. This “lack of cooperation” between traditional economic planners and climate officials is frequently mischaracterized as a mere “lack of capacity”. Consequently, many developing countries outline conditional and unconditional scenarios, as the uncertainty of international financial support serves as a major obstacle not only to the initial design, but also to the implementation of the ambitious systemic changes the strategies envisage.

To provide a clearer structure, the main challenges highlighted in LT-LEDS and related reports can be grouped into several categories (UNFCCC Secretariat, 2022, 2023; United Nations Environment Programme, 2025):

**Stakeholder engagement:** Stakeholder engagement often faces significant hurdles. There is frequently a lack of interest from groups not traditionally focused on climate change, including certain civil society and private sector organizations, because the consultation topics may not align with their direct non-commercial and commercial interests. Additionally, a “power imbalance” often persists during consultations, where groups with closer ties to financial resource allocation decisions tend to dominate the process, potentially discouraging more diverse or marginalized stakeholders from engaging meaningfully. In some cases, consultation processes are conducted as a one-off and are informational rather than iterative and co-creative, which limits ownership of LT-LEDS outcomes. To ensure that these strategies effectively guide national decisions, it is critical to move beyond passive consultation towards a model of deep ownership by key stakeholders and decision-makers. Establishing the LT-LEDS as a co-created vision ensures that the resulting pathways are not only technically feasible but also politically and socially durable, providing the necessary mandate for the difficult trade-offs required during long-term implementation.

**Financial and human resources:** Many developing countries report persistent funding gaps for core governance functions, such as data collection, scenario modelling, inter-ministerial coordination, and subnational engagement. A significant

challenge lies in the composition of the civil service: many government ministries are primarily staffed by administrative personnel or process managers, while lacking the specialized technical expertise required for complex long-term climate planning. This is compounded by limited, project-based funding, which can lead to fragmented efforts and high staff turnover, undermining institutional memory and the continuity of LT-LEDS implementation.

**Technical and organizational capacities:** Several Parties (United Nations Environment Programme, 2025) indicate that they lack specialist skills for long-term modelling, macro-fiscal analysis of transition options, and the design of regulatory instruments aligned with LT-LEDS goals. In addition, mandates between ministries are not always clearly defined, which can create overlaps or gaps in responsibility for LT-LEDS implementation.

In the following section, we examine how these capacity and governance gaps translate into concrete institutional barriers to LT-LEDS design and implementation, as well as identify opportunities for targeted support and reform.

The majority of developing countries indicate in their LT-LEDS that they face **financial challenges** and are reliant on external support, either from developed countries, private resources, or international bodies. For example, financial restraints affect reporting-related institutional capacities resulting from insufficient funding to establish the data-collection programmes required to fully design a reporting process. Financial constraints also affect human-capacity-related institutional arrangements, hindering the creation and implementation of expertise development programmes. In addition, financial limitations often curb efforts to raise the level of expertise of subnational government agencies and thus their ability to acquire the necessary knowledge for sectoral integration measures. Some developing countries struggle with a lack of data sharing between sectors, which prevents integrated planning needed for decarbonization. On a positive note, some developed countries specified in their LT-LEDS a commitment to supporting climate action through support for, or investment in, developing countries (United Nations Environment Programme, 2025). These commitments, when operationalized through climate finance, technology transfer, and capacity-building initiatives, can partially offset domestic resource constraints, but they remain uncertain and often short-term in nature.

Countries also report technical challenges in relation to involving enough stakeholders in the LT-LEDS design, implementation,

and review process, including unclear specific mandates, limited political buy-in from stakeholders, and difficulties in ensuring high political and public acceptance in the long run. For example, the Republic of the Marshall Islands faced technical and financial constraints over the lack of resources for estimating the level of GHG emissions associated with international transport and therefore for integrating concrete action strategies on this topic within its LT-LEDS (Marshall Islands, 2018; United Nations Environment Programme, 2025). Parties also identified areas in which emission reductions remain difficult because several technologies, such as flexible power systems to accommodate variable renewable energy generation, long-distance transport, and industrial processes, have not yet been widely commercialized (UNFCCC Secretariat, 2022, 2023). This technology gap directly affects the feasibility of certain long-term pathways and can make some scenario assumptions difficult to translate into near-term policy measures.

Challenges regarding human capacity are evident across three distinct levels of the LT-LEDS process. Specifically, gaps exist in the preparation of the strategies themselves, the design of policies and regulations needed to create an enabling environment, and the technical implementation of specific projects, such as renewable energy installations. In our previous report, 20 countries reported lacking a single coordination entity, leading to fragmented roles across different ministries (United Nations Environment Programme, 2025). Additionally, coordination entities noted that they often encounter two further challenges that stem from financial and human capacity inadequacies in developing countries' governments. Firstly, some government agencies have poorly qualified staff, and more skilled or educated personnel often opt for better-paying job opportunities elsewhere. Secondly, some countries' sectoral government bodies lack the institutional frameworks necessary to participate in dialogues regarding the implementation of LT-LEDS. Consequently, these countries rarely prioritize the lack in human capacity over other possible applications of their resources. The intersection of various institutional arrangements is evident here, as uncertainty regarding international financial support remains a major barrier to achieving more ambitious LT-LEDS. These constraints collectively limit countries' ability to maintain continuity across electoral cycles and to sustain long-term planning processes.

Two common institutional constraints hinder the determination of priorities for enhancing the regulatory framework: inadequate coordination among stakeholders and limited transparency in policy development. Even

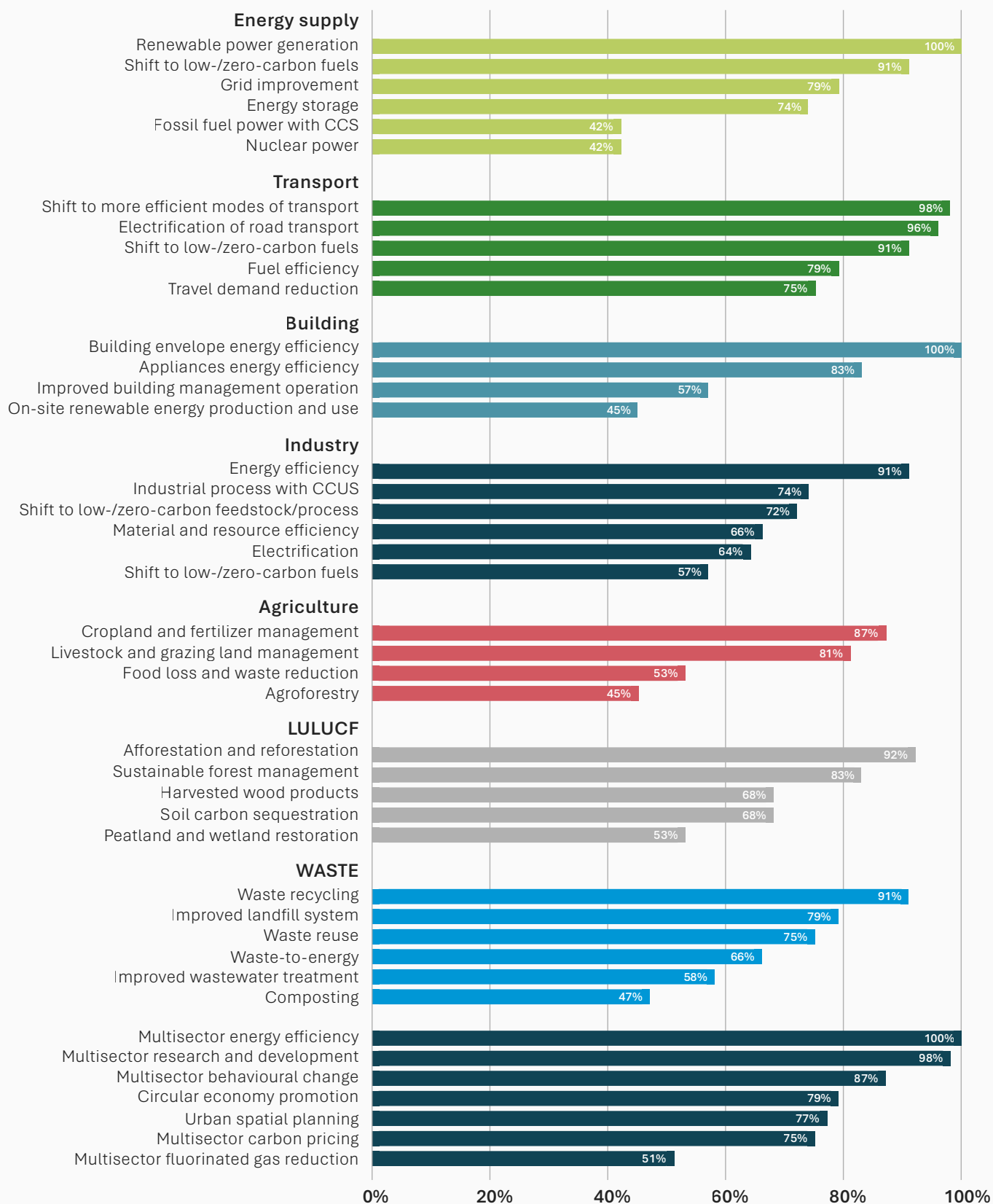
where coordination bodies exist, they often struggle to manage competing policy agendas between ministries in the absence of clear dispute-resolution mechanisms or find themselves overruled by higher authorities. Furthermore, the sustainability of these frameworks is often tested by political turnover; institutional coordination mechanisms frequently struggle to withstand major shifts in policy direction between successive national administrations. Evidence suggests, however, that strong subnational climate governance can provide essential resilience and stability, limiting the potential rollback of national climate commitments during political transitions. Another related regulatory and knowledge gap arises when technical staff lack the expertise required for complex long-term modelling. Beyond this technical shortfall, there is a systemic need to refine analytical methods and strengthen governance structures so that scientific evidence can more effectively inform, assess, and monitor climate policies. Addressing these gaps is essential for countries to translate LT-LEDS goals into concrete, evidence-based policy objectives that can withstand political cycles (United Nations Environment Programme, 2025).

Thus, these financial, technical, human, and regulatory barriers mean that many LT-LEDS remain aspirational documents rather than fully operational governance instruments. Addressing these gaps requires not only additional resources, but also deliberate reforms to mandates, coordination mechanisms, and participation practices, which are discussed in the subsequent sections on NDC alignment and governance pathways.

### **2.4.1 Key technologies and mitigation options highlighted in LT-LEDS and for achieving net zero**

The UNFCCC synthesis reports on long-term low-emission development strategies provide an indicative overview of the mitigation options that Parties most frequently communicate across sectors in their LT-LEDS (Figure 1). While the underlying methodology for quantifying the "share of mitigation options communicated" is not fully disclosed, the figure remains useful for understanding which technologies and measures currently dominate national net-zero narratives. Rather than reproducing or updating the calculations, this chapter therefore uses the UNFCCC figure for illustrative purposes and focuses on the governance implications of these technology choices (UNFCCC Secretariat, 2022). Figure 2-1 summarizes the mitigation options most frequently referenced in national LT-LEDS.

**Figure 2-1.** Mitigation options communicated in more than 40% of LT-LEDS; all submitted LT-LEDS in this synthesis report were screened for mitigation options.



Across the energy system, most LT-LEDS emphasize the large-scale deployment of renewable energy, the phase-down of unabated coal and other fossil fuels, and grid upgrades to integrate variable renewables, often combined with improved energy efficiency on the demand side. Transport-related options typically include modal shifts and public transport improvements, fuel economy standards, and the progressive electrification of vehicle fleets, with some strategies also considering sustainable fuels for aviation and shipping. In industry, countries highlight efficiency improvements, fuel switching, process innovation, and, for a smaller set of hard-to-abate activities, such as cement and steel, the possible role of carbon capture, utilization, and storage (CCUS) over the medium to long term.

Buildings-sector options mentioned in LT-LEDS range from stricter efficiency standards and better insulation to efficient appliances, clean cooking solutions, and electrified heating and cooling, all enabled by a low-carbon electricity supply. For AFOLU, many strategies prioritize reducing deforestation, enhancing forest sinks, climate-smart agriculture, and improved livestock and manure management, while waste-sector options include better collection and separation, landfill gas capture, recycling, and waste-to-energy technologies. Overall, these choices reflect countries' efforts to balance near-term, "no-regret" options, such as efficiency and renewable energies, with more uncertain or capital-intensive technologies, including hydrogen and CCUS, whose large-scale deployment will depend on future costs, social acceptance, and enabling infrastructure.

Despite this broad coverage, the emphasis on individual technologies differs markedly between Parties, shaped

by national circumstances, development priorities, and institutional capacities. This variation underscores the importance of robust governance frameworks that can manage technology risks, avoid lock-in to high-carbon infrastructure, and keep multiple options open as costs and feasibility evolve over time. It also highlights a gap: while many LT-LEDS clearly articulate technology portfolios, fewer specify the decision points, regulatory reforms, and investment signals needed to bring these options to scale, reinforcing the need for stronger links between technology choices, institutional arrangements, and implementation roadmaps.

Finally, options targeting short-lived climate pollutants (SLCPs)—for example, methane reductions from agriculture, fossil fuel production, and waste—are referenced less systematically than carbon-dioxide-focused measures, even though they can deliver rapid near-term temperature and air-quality benefits. Strengthening the treatment of SLCP-related technologies and practices in future LT-LEDS would therefore complement long-term net-zero objectives and help close the ambition gap in the 2030 time frame. This is particularly relevant for non-CO<sub>2</sub> emissions from agriculture, where technical mitigation options that only improve the greenhouse gas efficiency of production face upper limits if global food security is to be preserved. A more systemic transformation of agricultural systems—including shifts in demand, production methods, and diversification of crops and livestock—can enable deeper and more sustainable reductions in agricultural methane and other non-CO<sub>2</sub> emissions, reinforcing the messages highlighted in Chapter 2.

## 2.5 NDC & LT-LEDS

Having a long-term goal and identifying the pathways to achieving it is useful for determining policy direction. However, any attempt to predict the future beyond a few years is, by its very nature, fraught with uncertainty. Technological developments and scientific research can progress quickly, rendering alternative actions more viable or necessary. Public opinion and the political landscape can also change rapidly. The ability of countries to adjust and adapt to changing future circumstances is key, but also challenging. Effective climate policy must be resilient to external dynamics, combining flexibility with regular adjustments. Accordingly, long-term strategies cannot be

one-off documents but rather require regular review and updating in light of new and better information, at least every five years, so that they can continue to inform policy decisions (Velten et al., 2022). This iterative process reflects the five-year ambition cycle established under Article 4.19 of the Paris Agreement.

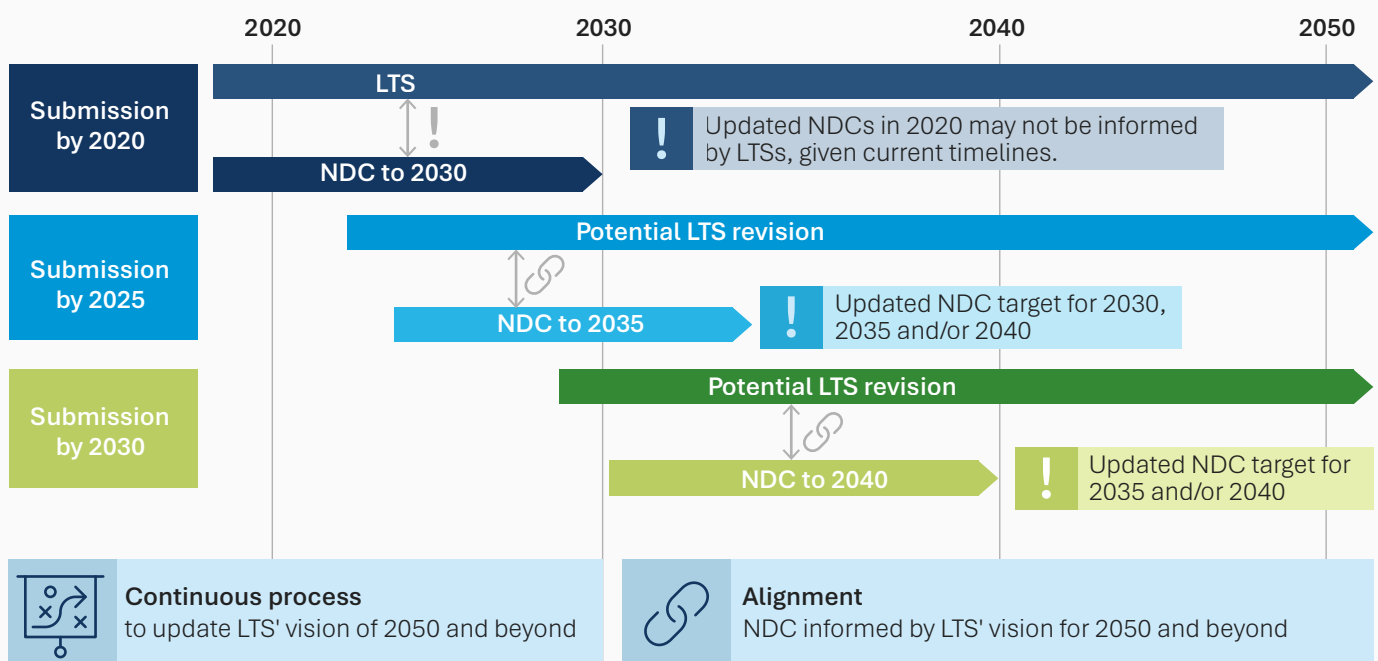
UNFCCC and our study have emphasized that the primary value of an LT-LEDS lies in providing a coherent pathway for the five-year NDC cycles. Rather than being standalone documents, NDCs should be seen as the short-term milestones aligned with the long-term vision of the

LT-LEDS. Simultaneously, the five-year NDC submission window offers a critical institutional opportunity to update LT-LEDS, allowing countries to incorporate technological advancements and socio-economic changes from the preceding period. As highlighted by the Secretariat (UNFCCC Secretariat, 2022, 2023), if Parties collectively began reducing emissions with a view to achieving their 2050 targets, and those reductions remained constant over the next two decades, the average emission reduction rate would be less pronounced than currently foreseen. Many countries (approximately 45 per cent of those that have submitted LT-LEDS), including Germany, France, and the United Kingdom of Great Britain and Northern Ireland, Colombia, Fiji, Nepal, the Republic of Korea, South Africa, the Republic of Marshall Islands, Thailand, and Tonga, state that they will review their LT-LEDS every five years in line with their NDC development cycle. However, to date, only a subset of Parties has operationalized this commitment in practice; most LT-LEDS merely indicate an intention to align with future NDC updates rather than specifying concrete procedures, timelines, or responsibilities for doing so (United Nations Environment Programme, 2025).

the course of the next ten years and to emphasize the importance of linking the LT-LEDS reporting process to the update of NDCs and other climate-relevant policies and laws. LT-LEDS and NDCs are closely linked and should be mutually reinforcing. This relationship forms an “iterative cycle,” where the long-term vision of the LT-LEDS informs the level of ambition for subsequent NDCs every five years, as we recommend. In the best case, the update of the LT-LEDS should happen shortly before the NDCs are updated so that the long-term goals can inform the choice of NDC targets and sectoral action strategies. For countries that have not yet submitted LT-LEDS, preparing such strategies is an essential first step towards constructing this iterative cycle. For countries that already have LT-LEDS in place, the priority is to systematically link LT-LEDS goals, sectoral pathways, and policy instruments to their NDCs and related implementation plans, so that both instruments collectively contribute to significant global emission reductions by 2050. By “backcasting” from the 2050 goal, countries can better determine the short-term targets and concrete actions required in the near term to stay on track. The legal status of targets also varies, with countries typically categorizing them as a “target in law,” “target in proposed legislation,” or a “target in policy” (Català et al., 2050).

We developed Figure 2-2 to demonstrate how the NDC revision cycle can be informed by a long-term vision over

**Figure 2-2:** Proposal for ongoing LTS revision and alignment with the NDC cycle



Source: inspired by (Hnas et al., 2020) publication.

Consequently, we argue that it is advantageous for countries' NDCs to be informed by and aligned with LT-LEDS to ensure consistency and avoid the lock-in of carbon-intensive behaviours, technologies, and policies (United Nations Environment Programme, 2025). By clearly communicating their plans to achieve net-zero emissions by mid-century, countries can unlock and drive more ambitious national climate action through updated NDCs over the next decade (WRI n.d.).

### 2.5.1 Best-practice examples and transformation readiness

Several LT-LEDS illustrate how this iterative LT-LEDS–NDC relationship can be operationalized through a whole-of-government and whole-of-society approach. Costa Rica, for example, structures its decarbonization plan around ten sectoral and cross-cutting axes, each linked to concrete policies and investment needs, which then inform successive NDC updates. Mexico combines long-term net-zero and SLCP targets with detailed sectoral pathways and has used these to underpin NDC revisions and international cooperation priorities (United Nations

Environment Programme, 2025). Fiji's LT-LEDS defines multiple conditional and unconditional low-emission scenarios that are explicitly linked to NDC trajectories, supported by dedicated coordination mechanisms and stakeholder processes. These examples demonstrate that, when institutional capacities are in place, LT-LEDS can move beyond high-level vision statements and become practical steering tools for successive NDCs and related policy cycles (Costa Rica, 2019; Fiji, 2019; Mexico, 2016).

Fiji also links its LT-LEDS to other national development goals, such as poverty alleviation and sustainable development. In addition to their conditional and unconditional scenarios, Fiji includes a high ambition scenario, which aims to adopt new and more ambitious policies and financing measures to achieve significant emissions reductions by 2050, as well as a very high ambition scenario, which aims for a minimum of net-zero or net-negative emissions by 2050 in most sectors. Fiji applies four scenarios—BAU unconditional, BAU conditional, high ambition and very high ambition—for each sector in its strategies to Analyse and identify the specific measures and targets (Fiji, 2019; United Nations Environment Programme, 2025).

## 2.6 Pathways to long-term and sustainable climate governance through LT-LEDS: conclusion and policy recommendations

A core function of LT-LEDS is to chart a pathway to the future, enabling informed decisions on near- and long-term policies to be made in light of the desired changes. Not all existing LT-LEDS are currently able to do so. Many LT-LEDS provide insufficient information on how to guide policymaking towards achieving the targeted long-term climate actions. Descriptive documents generally lack an indication of the role and timing of specific technologies, practices, and lifestyle changes, as well as the corresponding requirements. The same is true of strategies with scenarios that do not achieve the long-term climate target. Most strategies do not identify when to decide on which path to follow or provide sufficient sectoral data to illustrate changes in the energy mix or agricultural practices, or even the quantified impacts of the different pathways. Nor do they identify decision points regarding enabling conditions. For example,

they do not specify when specific technologies need to be commercially available or when infrastructure needs to be in place. Consequently, these LT-LEDS cannot provide clear strategic guidance for the near term. To ensure that future strategies fulfil this function, greater harmonization and mandatory information on detailed pathways and decision points are required (Velten et al., 2022).

Arguably, the true value of LT-LEDS lies in their impact on national climate policymaking. A strategy may look good on paper, presenting a detailed and plausible vision of the future. However, it may fail to influence the actual measures and policy instruments needed to achieve the wide-reaching economic and structural changes required. Thus, the potential power that LT-LEDS can wield as drivers for ambitious climate action depends on the role they are given in a national governance

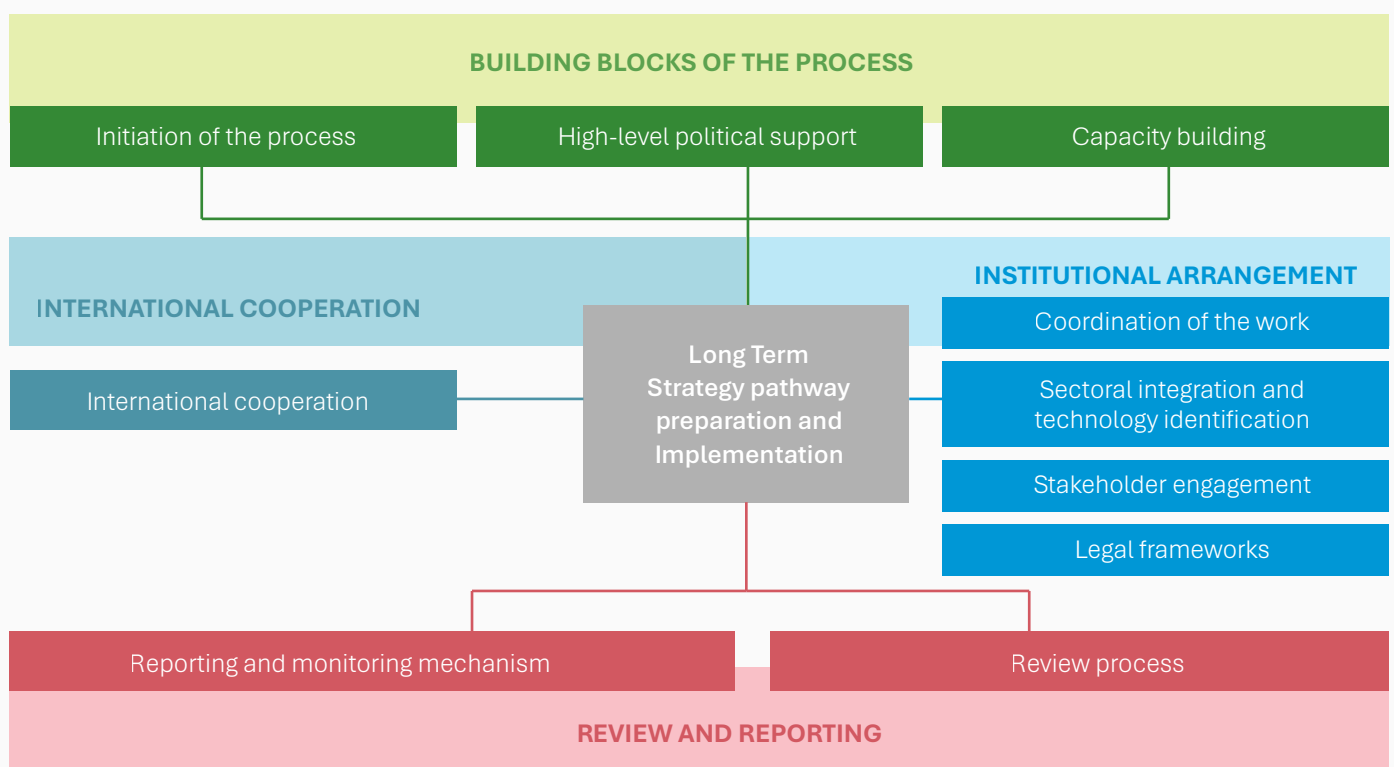
system, including their overall relevance (Duwe & Iwaszuk, 2019; Ross et al., 2021b; Rüdinger et al., 2018). LT-LEDS are a constant work in progress. Thus, from a domestic perspective, LT-LEDS are country-driven policy instruments that help shape and influence national decision-making processes. From an international perspective, LT-LEDS support the global goal of reducing GHG emissions. In order to achieve this, it is essential to include institutional arrangements and governance mechanisms, to maximize their effectiveness in design, implementation, and review. The findings show that certain institutional arrangements play a more important role for some countries than for others, depending on their national circumstances. On this basis, this section outlines key policy recommendations for strengthening long-term and sustainable climate governance (United Nations Environment Programme, 2025).

process for the LT-LEDS. In this context, high-level political support and capacity-building efforts should not be overlooked, notably the training of government agency staff to increase their technical and managerial skills.

Our analysis of countries’ LT-LEDS identified that strengthening institutional arrangements invariably requires heightened efforts on several fronts: coordination across different levels of government and input from governmental and non-governmental parties; integration of strategies into sectoral and cross-sectoral programmes and projects, and identification of the required technologies; engagement of a broad range of stakeholders through consultation campaigns or participatory policy processes, to elicit their input; and ambitious initiatives to revise regulatory frameworks and streamline legislative provisions (United Nations Environment Programme, 2025).

As a first step, countries could consider identifying key factors and conditions that help to initiate the development

**Figure 2-3:** Governance steps for LTS pathways development and implementation<sup>1</sup>



Source: Inspired from Elliott, C., Worker, J., Levin, K., & Ross, K., 2019. Good Governance for Long-Term Low-Emissions Development Strategies. World Resources Institute, Washington, DC

<sup>1</sup> In this framework, “initiation of the process” refers to the early scoping and mandate-setting phase in which countries clarify the role of LT-LEDS within existing planning processes, identify key actors and questions, and secure an initial political signal to proceed. It therefore operates alongside high-level political support and capacity-building as a core building block of the process.

### 2.6.1 LT-LEDS governance framework

Based on Figure 2-3 above (United Nations Environment Programme, 2025), we propose a recommendation framework for the entire process through which countries can integrate institutional arrangements to ensure the longevity of their LT-LEDS development, implementation, and updating strategies. The elements of this framework synthesize the governance patterns, gaps, and good practices identified in the preceding sections on capacities, institutional barriers, and NDC–LT-LEDS alignment. Innovative approaches to national governance—anchored in specific country circumstances—are necessary to ensure an effective transition to net zero consistent with LT-LEDS guidelines. The development of a Long-Term Strategy (LTS) begins with a foundational phase centred on initiation and high-level political mobilization. This process is typically triggered by identifying key drivers through awareness-raising events and meetings that help build the necessary momentum for reform. Achieving high-level political buy-in is essential and often coordinated by a lead institution such as the Ministry of Environment, Foreign Affairs, or Planning.

Given the cross-sectoral nature of low-emission development, it is important to ensure integration with national development planning rather than establishing parallel structures. In this regard, Ministries of Economy or Planning should ideally co-lead the LTS process, with the Ministry of Environment providing critical inputs on climate priorities and technical aspects.

From country experiences and initiatives such as the 2050 Pathways Platform, this initial phase also involves clarifying the strategic scope of the LTS, situating it within the existing policy and planning framework, and identifying key policy and research questions to inform subsequent modelling and analytical work. Establishing robust governance structures specifically designed for long-term climate planning helps overcome political fluctuations and manage the trade-offs inherent in transformative change, ensuring policies remain aligned with long-term climate objectives (UNFCCC Secretariat, 2022, 2023; United Nations Environment Programme, 2025; Velten et al., 2022). This political support is essential for reinforcing alliances and ensuring that climate policy is reflected in broader governmental actions.

Science must play a central role in these processes, helping to design effective policies, compare different options and pathways, and assess and monitor their implementation. Strengthening local ownership of data, models, and

scenarios within the national context is critical, so that national strategies are guided by country-driven and locally grounded evidence (DDP Report, 2025). To bridge the gap between policy and practice, countries must prioritize capacity-building by investing in the technical modelling and managerial skills of government staff to ensure that the strategy is grounded in robust analysis (United Nations Environment Programme, 2025), Figure 2-3.

Inclusive processes, when supported by strong mandates, explicitly framed by a long-term perspective, and informed by country-driven scientific evidence, act as key enablers for the adoption of ambitious national climate action. LT-LEDS identify capacity-building as a cross-cutting issue that is the overarching enabler for adaptation and mitigation action and fulfilment of commitments. LT-LEDS also highlight the importance of capacity-building for facilitating technology development, access to climate finance, and community engagement. Overall, capacity-building is deemed crucial to the implementation of LT-LEDS operational strategy (UNFCCC Secretariat, 2022, 2023).

Once the foundation is set, the process shifts towards institutional arrangements and implementation, requiring a “whole-of-government” approach to coordinate various agencies and non-governmental stakeholders. This involves integrating net-zero targets into specific sectoral programmes and strengthening legal frameworks to streamline regulations. To ensure mainstreaming, it is vital to embed climate goals into key national legislation and planning tools beyond climate policy, such as long-term economic visions or economy-wide development plans. Public policies should play a critical role in accompanying structural economic and industrial shifts and strengthening synergies between climate, industrial, and economic agendas. At a time when most countries are developing or redeveloping their industrial policies, setting benchmarks for such policies against required long-term economy-wide transformation objectives, such as those implied by decarbonization, would provide a valuable tool to inform the design of ambitious long-term climate policies that are compatible with sustainable economic growth (DDP Report, 2025; Velten et al., 2022).

To complement domestic efforts, international cooperation, including market-based mechanisms and technology partnerships, can be utilized to help reach mitigation commitments. Effective mobilization of international cooperation in support of climate ambition should enable the broad deployment of the most advanced and best available technologies across countries, which is a critical

necessity to support country transitions. New international processes must therefore be established to allow for greater awareness of existing technologies and to connect relevant countries with one another to support effective diffusion (DDP Report, 2025).

Finally, the longevity of the strategy is secured through continuous monitoring, reporting, and review cycle. This stage is critical for creating the conditions necessary to benchmark and monitor short-term action against long-term development and climate goals. This can be achieved through the preparation of LT-LEDS with a high level of sectoral detail, while maintaining an explicit connection with NDCs or sectoral policies. By utilizing existing data collection mechanisms to track progress, countries can establish a feedback loop that incorporates new methodologies and data, allowing them to adjust their course of action and improve their LT-LEDS over time (United Nations Environment Programme, 2025), Figure 2-3.

In addition, many LT-LEDS highlight the need to further strengthen countries' international cooperation to accelerate the deployment and application of critical technologies, including through coordinated planning and the mainstreaming of technological innovation. Partnerships for advanced technology research and development are frequently mentioned as an effective way to facilitate the widespread deployment of new inventions. International cooperation is underscored as important for enabling the large-scale adoption of clean technologies because accessing such technologies often involves international collaboration and technology transfer (UNFCCC Secretariat, 2022, 2023). For instance, Mexico, Canada, and the United States of America collaborated closely during the formulation of their LT-LEDS to share and compare experiences (Canada, 2016; Mexico, 2016; United States of America, 2021).

Achieving net-zero emissions requires a long-term and sustainable approach to climate governance **built around the development and implementation of ambitious LT-LEDS and supported by**

- Strengthening institutional arrangements through formal legal mandates.
- Building capacity and providing resources.
- Ensuring inclusive and effective stakeholder engagement.
- Integrating LT-LEDS into national development plans and policies.

- Formalizing stakeholder consultations by hosting them within a governmental entity with a clear mandate and guidelines to document outcomes.
- Utilizing professional, neutral facilitators to manage complex multi-stakeholder dialogues and ensuring that, for large, diverse countries, a mix of centralized and delegated coordination is used to reach subnational levels.
- Implementing a systematic capacity-building framework, such as the ADDIE model (Analyse, Design, Develop, Implement, Evaluate), to ensure that knowledge delivery is structured, results-oriented, and continuously improved.
- Actively involving the financial and insurance sectors by identifying and presenting specific investment opportunities for each net-zero priority, which is a prerequisite for mobilizing private-sector capital.

These actions can be sequenced over time. In the immediate term, countries can focus on establishing or strengthening lead institutions, clarifying mandates, and launching capacity-building efforts. In the medium term, aligning LT-LEDS with NDC cycles, revising regulatory frameworks, and scaling up investment frameworks become critical. Over the longer term, continuous learning, innovation, and international cooperation will be needed to keep LT-LEDS relevant as technologies and socio-economic conditions evolve.

Besides long-term guidance, LT-LEDS can also contribute to medium-term policy planning. The acceleration of national transitions in the next decade requires comprehensive policy packages, such as multiple issues and policy coordination across a variety of policy actions, including national development and investment plans. National policies must build enabling conditions for immediate emission reductions where technical options are available. They should also encourage the longer-term structural changes needed by providing targeted support for infrastructure development, accelerating the market readiness of new technical options, and encouraging behavioural change (DDP Report, 2025).

Well-designed LT-LEDS have the potential to facilitate policy planning and encourage international collaboration on specific issues by identifying pathways and investment requirements for each sector. For example, Fiji aims to reach net-zero carbon emissions by 2050 across all sectors of its economy (Fiji, 2019). Potential solutions for increased international cooperation include establishing forums to enhance consensus among countries on how to tackle

climate change and share lessons learned (United Nations Environment Programme, 2025).

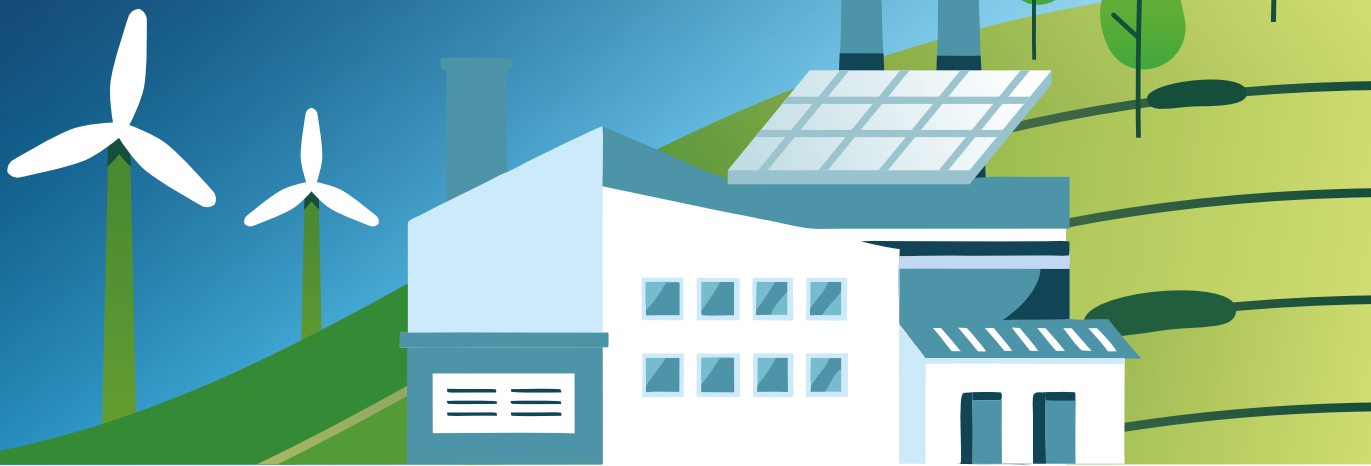
The analysis presented in this chapter shows that the effectiveness of LT-LEDS depends less on the existence of long-term targets and more on the institutional arrangements that translate these targets into concrete policy processes and investment signals.

In summary, long-term planning provides a foundation for current decisions. Presenting a clear vision of a climate-neutral future and the steps required to achieve it helps everyone involved to understand the scope of the net-zero transformation and its potential impacts along the way. Net zero is achieved through collective practices,

inclusive systems, and community-led change, not just infrastructure or technology. As our analysis showed, some countries have enshrined their net-zero target in a climate law (United Nations Environment Programme, 2025). Long-term planning should outline crucial decision points, map existing, and planned solutions, and identify the actions needed today to make new solutions a reality in the future. With sufficient buy-in from leaders and government officials, long-term strategies provide a critical reference point for political decisions across all policy areas (and potentially spanning electoral terms), offering additional certainty to businesses and private citizens regarding their choices, for example, investments, practices, or lifestyle changes (UNFCCC Secretariat, 2022, 2023; United Nations Environment Programme, 2025; Velten et al., 2022).

# 3.

## National Pathways to Net Zero: Key Characteristics and Policy Insights



### 3.1 Introduction

Chapter 2 highlights the importance of establishing governance structures and processes that are suited to the specific demands of the transition to net zero. It emphasizes the need to ensure that diverse perspectives and action levers are represented—from government, businesses, civil society, and scientists—while keeping a long-term vision at the heart of decision-making. It highlights the need to establish cutting-edge governance structures specifically designed around climate objectives to respond to coordination needs between sectors and actors, as well as to address trade-offs and inevitable political negotiation. In this context, a country-driven vision of the net-zero transition, such as the LT-LEDS, is identified as a key instrument to guide action, shape investment decisions, and ensure policy coherence with the net-zero objective. While Chapter 2 focuses primarily on governance arrangements and institutional capacities for LT-LEDS, this chapter examines the structural transformations implied by national net-zero pathways, analyses the key priorities for short-term action, and assesses the last decade of climate action against these priorities.

The approach developed in this chapter recognizes that long-term trajectories are context-specific, and should reflect national economic structures, institutional capacities, technical potentials, and development priorities. However, the cross-country analysis of country-driven net-zero pathways yields robust conclusions about long-term transformations and short-term actions that have a broad validity and can serve as a generic guide for action. Indeed, although pathways, rhythms, timelines, trade-offs, and policy instruments will differ significantly between countries, the national pathways to net-zero converge on common and structural conditions that are necessary for the net-zero transition (Briand et al., 2026). These insights can serve as a guiding framework to help countries structure their reflections, define their own targets, and design strategies adapted to their national circumstances, as well as a framework for assessing progress towards carbon neutrality (Waisman et al, 2026).

The analysis presented in this chapter was developed by in-country experts from the Deep Decarbonization Pathways

(DDP) network<sup>2</sup>. The relevance, robustness, and neutrality of these assessments are ensured by the authors' detailed knowledge of their country, their deep understanding of policy dynamics given their direct involvement in national climate strategies and policies, and their analytical and scientific expertise as academic researchers. In an attempt to connect the climate and development agendas at a national level, the long-term pathways that form the basis of the analysis presented in this chapter assess the interplays between emission pathways, their underlying sectoral drivers, and national socio-economic objectives.

Section 3.2 highlights key long-term transformations required to reach net-zero emissions, while Section 3.3 highlights policy recommendations for short-term actions that are necessary to initiate and anchor these

transformations. These analyses build on the DDP Report 2024 which analyses detailed scenarios from ten countries collectively representing nearly half of the world's population and more than half of today's global emissions<sup>3</sup> (DDP, 2024). These scenarios explore national trajectories towards carbon neutrality by 2050 or by a later date, depending on specific official commitments adopted by countries (2060 in Nigeria, Indonesia, and China, and 2070 in India). Section 3.4 examines whether the national climate policies implemented since the adoption of the Paris Agreement align with these insights, with the aim of assessing progress and identifying the remaining challenges. This analysis builds on the DDP Report 2025 grounded on a detailed analysis of climate action in 21 countries, representing a diversity of geographies, levels of development, and sizes<sup>4</sup> (DDP, 2025).

## 3.2 Long-term transformations in national pathways to net zero

Evidence from country-level net-zero assessments consistently indicates that carbon neutrality cannot be achieved through isolated technological substitutions alone. Instead, it requires long-term transformations affecting energy systems, industrial production, transport, buildings, and land-use practices. Although these transitions differ according to national circumstances, several common dynamics emerge across countries. These include a relentless reduction of fossil-fuel use in energy and industrial systems, aligned with socioeconomic priorities; the strengthening of land-based carbon sinks while safeguarding other land-use functions, such as food security and biodiversity protection; and the need for dedicated measures to reduce non-CO<sub>2</sub> emissions from agriculture.

### 3.2.1 A relentless decrease in fossil-fuel use

Daily activities—including living in buildings, the production and consumption of goods and services, and the movement of people and freight—remain heavily

reliant on energy use, particularly fossil fuels. Across all national pathways assessed, achieving net zero requires a substantial reduction in the share of fossil fuels within final energy consumption (Figure 3-1). At the same time, these trajectories differ significantly between countries. Variations reflect differing patterns of energy demand shaped by national socio-economic conditions, domestic energy system structures, development priorities, and target dates for achieving carbon neutrality.

Across most countries covered by the DDP scenarios, fossil fuels currently represent roughly 70 per cent of final energy consumption. In pathways consistent with net zero, this share declines progressively over time, falling to around 30 per cent or less by 2050 (Figure 3-1). The pace and shape of this transition nevertheless differ across countries depending on national circumstances. In Indonesia and India, for example, the reduction in fossil-fuel dependence occurs more gradually despite a clear downward trend, reflecting rapidly increasing energy demand linked to development needs, as well as later carbon-neutrality targets of 2060 and 2070, respectively.

<sup>2</sup> <https://ddpinitiative.org/>

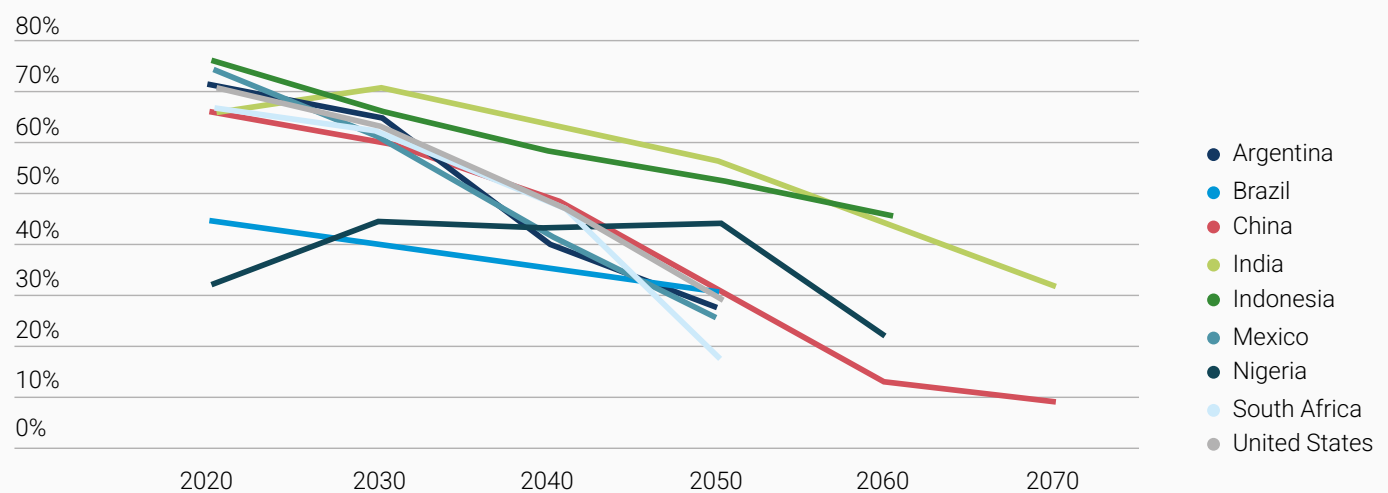
<sup>3</sup> Argentina, Brazil, China, India, Indonesia, Mexico, Nigeria, Senegal, South Africa, and the United States

<sup>4</sup> Argentina, Brazil, Canada, China, Costa Rica, Côte d'Ivoire, Dominican Republic, France, EU, Germany, Guatemala, India, Indonesia, Japan, Kazakhstan, Mexico, Nigeria, Senegal, South Africa, Thailand, United States

Brazil illustrates a situation where abundant natural resources allow for an already quite low level of fossil-fuel use and therefore a more gradual reduction in fossil-fuel use to reach similar levels to those seen in the other countries by 2050. Nigeria is an example of a country where the current

dominant role of traditional biomass and delayed access to key energy services trigger an inverted-U shape, where the use of fossil fuels temporarily increases before decreasing to low levels in the second half of the century.

**Figure 3-1:** Share of fossil fuel in final energy consumption (%)



Source: Fossil fuels are coal, natural gas and oil final derivatives. In India, fossil fuel shares have been extrapolated for the years 2060 and 2070 based on Garg et al., 2024. ([https://psa.gov.in/CMS/web/sites/default/files/publication/ESM%20Report-2024\\_New-21032024.pdf](https://psa.gov.in/CMS/web/sites/default/files/publication/ESM%20Report-2024_New-21032024.pdf))

The importance of the reduction in fossil-fuel use also results notably from the consistent assessment of a limited role of Carbon Capture and Storage (CCS) in national pathways to net zero, mostly limited to specific uses in industry (Annex 1 - CS 1.1.1)<sup>5</sup>. Detailed assessments of technical feasibility, geological availability, spatial constraints, economic viability, and deployment timelines suggest that CCS is likely to play only a relatively limited role in cumulative emission reductions by 2050 across national pathways to net zero.

The analysis highlights two main factors that help ensure alignment between fossil-fuel reduction and domestic socio-economic priorities.

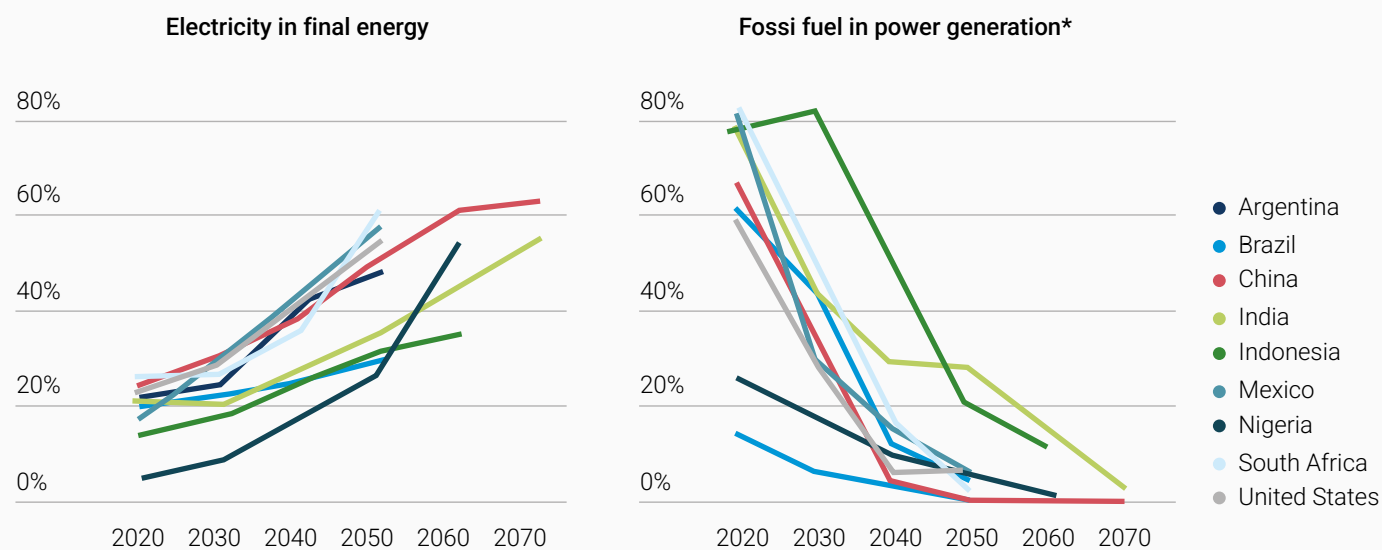
First, a common feature across national pathways to net zero is the large-scale electrification of end uses in sectors such as buildings, transport, and industry (Figure 3-2, left). In many countries assessed, electricity therefore becomes the main form of final energy consumption by 2050, or by the respective target year for carbon neutrality. However, the extent and pace of electrification differ depending on national circumstances. In Brazil and Indonesia, for example, electrification progresses more slowly and plays a comparatively smaller role because biomass remains widely available and continues to supply a significant share of energy demand (Figure 3-2, left). At the same time, this expansion of electricity use is accompanied by a major decline in the role of fossil fuels in power generation, with

<sup>5</sup> Annex 1 refers to country Case Studies (CS) developed by in-country experts from the Deep Decarbonization Pathways (DDP) network and published in *Making it Happen: National Pathways to Net-Zero* (2024) and *A Decade of National Climate Action: Stocktake and the Road Ahead* (2025). The annex provides a brief overview of each case study, together with references to sources where more detailed information can be found.

electricity systems projected to become largely fossil-free by the time countries reach their carbon neutrality targets (Figure 3-2, right). The pace of this transition nevertheless varies across countries. In India, for instance, the slower decline in fossil-fuel-based electricity generation between

2040 and 2050 reflects continued investment in gas-fired power capacity to support the rapid scale-up of renewable energy and maintain grid reliability before fossil fuel use in the sector declines to near zero by 2070 (Annex 1 - CS 1.1.2).

**Figure 3-2:** Share of electricity in final energy consumption and share of power generation from fossil fuels (%)



\* This share includes abated and unabated fossil fuel power generation.

In end-use sectors, national pathways to net zero also depend on systemic shifts in energy consumption patterns, requiring profound changes in infrastructure, social and economic organization of human activities, and patterns of behaviour. These changes are necessary to ensure that essential socio-economic functions—including mobility, housing, food, production, consumption, and access to services—can continue to expand while requiring lower overall energy demand. Achieving this objective therefore involves more than the substitution of existing technologies with more efficient equipment; it also requires structural changes in the way systems are designed and organized. In the transport sector, for example, this includes better integration between land-use planning and transport infrastructure development to improve access to daily

activities through lower-carbon modes such as walking, cycling, and public transport, thereby reducing reliance on private cars and energy-intensive mobility systems. In buildings, reducing energy demand depends in part on bioclimatic design approaches that limit heating and cooling needs, alongside Behavioural changes affecting household energy consumption. More broadly, shifts in production and consumption systems imply progress towards circular-economy approaches<sup>6</sup>, including changes in product design, industrial organization, and material-use patterns that support the reduction, repair, reuse, and recycling of products and raw materials (Annex 1 - CS 1.1.3).

6 Learn more about 9Rs circular strategies (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover), <https://www.unep.org/circularity>

### 3.2.2 Maximizing carbon sink in the land-use sector

Although national circumstances differ, all pathways assessed include net-negative CO<sub>2</sub> emissions from the land-use sector by 2050. This reflects the distinctive role of the sector in removing carbon from the atmosphere through natural processes, notably by increasing carbon sequestration in forests, as well as in croplands and grasslands, without depending primarily on technological carbon removal solutions.

The increase in CO<sub>2</sub> absorption in forestlands is driven by the expansion of forest area—through reduced deforestation and increased afforestation and reforestation—as well as by improved management of existing forests. The specific drivers of these negative emissions and the corresponding transformations will vary by country, depending on the specific national circumstances defining the natural potential for negative emissions. Country pathways nevertheless differ in the specific land-use transformations that drive negative emissions. In Brazil, reducing deforestation is the dominant mitigation lever and represents a major source of negative emissions, placing land-use action at the centre of the country's climate strategy. In India, additional carbon removals are driven largely by the expansion of agroforestry systems on croplands, which also contribute to improved soil conditions, greater resilience for farms, and more diversified sources of income for smallholders. In Indonesia, the transition from net emissions to a net carbon sink is mainly supported by efforts to curb deforestation and forest degradation, combined with peatland and mangrove restoration and the expansion of forest cover through afforestation, reforestation, and agroforestry practices (Annex 1- CS 1.2.1).

The assessment of national pathways also underlines that transformations in the land-use sector—and more broadly across land-use systems, including agriculture—must be adapted to country-specific circumstances, particularly given interactions and competition between different land uses. Unlocking the mitigation potential of the sector therefore depends on balancing climate objectives with other essential functions, including food security, rural livelihoods, ecosystem resilience, and biodiversity protection. Because ecological conditions, agricultural systems, and socio-economic realities differ widely across countries, the strategies capable of reconciling these objectives are inherently context-dependent. In Brazil, for example, restoring degraded grasslands can help substantially reduce pressure for deforestation while maintaining agricultural output. In India, expanding support for agroforestry practices can improve soil quality in degraded agricultural areas while also diversifying income opportunities for farmers.

### 3.2.3 Addressing non-CO<sub>2</sub> emissions in the agriculture sector

In national pathways to net zero, the reduction of non-CO<sub>2</sub> emissions from energy—notably methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) emissions associated with fuel extraction, transport, processing, and combustion—appears essentially as a co-benefit of actions supporting the transition away from fossil fuels (Annex 1- CS 1.3.1). This means that non-CO<sub>2</sub> emissions from this sector decline sharply in most countries, even without the need for additional mitigation measures beyond those adopted to support a relentless decrease of fossil-fuel consumption (see section 3.2.1).

On the other hand, the net-zero pathways focused on CO<sub>2</sub> emissions show little to no reduction in non-CO<sub>2</sub> emissions from agriculture. This represents a critical gap, because CH<sub>4</sub> and N<sub>2</sub>O account for 7–30 per cent of total GHG emissions in 2020 in the countries studied, and the IPCC highlights that limiting warming to 1.5°C requires deep reductions in non-CO<sub>2</sub> emissions by mid-century, alongside CO<sub>2</sub> neutrality. Further specific action is therefore needed to proactively reduce these agricultural non-CO<sub>2</sub> emissions, in a way that is aligned with rural livelihoods and food security, given that primary agriculture employs 1.23 billion people and supports the livelihoods of 3.83 billion people globally.

Methane emissions in agriculture primarily originate from enteric fermentation in ruminant livestock, manure management, and rice cultivation, while nitrous oxide emissions are mainly linked to livestock waste and fertilizer application. Reducing these non-CO<sub>2</sub> emissions therefore requires targeted measures focused directly on the activities that generate them. In Brazil, for example, national pathways assume a 30 per cent increase in average cattle carcass weight by 2050, which would lower the emissions intensity of beef production. They also project a reduction in fertilizer application rates compared to current average levels of approximately 60 kg/ha.

At the same time, the analysis indicates that improving the greenhouse gas efficiency of agricultural production alone is unlikely to deliver sufficiently deep reductions in non-CO<sub>2</sub> emissions while maintaining global food security objectives. Achieving larger reductions will therefore require broader transformations across agricultural systems, including changes in production practices, consumption patterns, and greater diversification of crops and livestock systems (Annex 1 - CS 1.3.2).

## 3.3 Short-term actions in national pathways to net zero

Section 3.2 has highlighted the essential role of diverse transformations to reach carbon neutrality. Taken together, this picture highlights that carbon neutrality should not be approached as the sum of independent sectoral shifts but rather as a coordinated reconfiguration of interconnected systems. Energy decarbonization reshapes land-use dynamics through bioenergy and electrification needs; land-use choices influence residual emissions and carbon sinks that condition the pace of industrial mitigation; and tackling non-CO<sub>2</sub> agricultural emissions requires aligning productivity, dietary trends, and ecosystem management with broader climate and development objectives. These transformations therefore interact structurally, with trade-offs and synergies that must be anticipated and governed coherently.

Because long-term transformations are deeply interconnected, national net-zero pathways underscore that short-term policies must be both aligned with long-term objectives and coordinated across sectors within a coherent policy framework.

Carbon neutrality requires accelerating immediate emission reductions in sectors where technical solutions are already available, while preparing the enabling conditions for long-term deep emission reductions. It also requires strengthening synergies between climate, industrial, and economic agendas, and managing the social impacts of the transition, notably with regard to the most vulnerable. From a policy standpoint, addressing these multiple objectives in a balanced way calls for the adoption of comprehensive policy packages that combine complementary actions within a consistent policy framework (Briand et al., 2026).

### 3.3.1 Triggering immediate emission reductions

The assessment of national pathways to net zero indicates that rapid emission reductions are necessary to align countries with long-term carbon-neutrality objectives. Such reductions can be achieved where policy, regulatory, and market conditions support the large-scale deployment of mitigation options that are already available. Across the countries analyzed, three sectors consistently emerge as priorities for near-term action: electricity generation, passenger transport, and land use.

In each case, low-carbon solutions are already technically mature, economically competitive in many contexts, and capable of being deployed at scale.

Rapid decarbonization of the power sector plays a particularly important role in national pathways to net zero. In most countries, electricity generation remains the largest source of energy-related emissions. At the same time, access to low-carbon electricity is a key enabling condition for reducing emissions in other sectors where electrification represents one of the most effective decarbonization pathways (see section 3.2.1). In many countries, renewable electricity sources—including hydropower, solar, wind, and biomass—are already cost-competitive with fossil-fuel alternatives, suggesting that high costs are not the primary barrier to their expansion. Instead, country analyses point to the importance of targeted policy measures and market reforms that can accelerate investment and strengthen incentives for low-carbon electricity production. Depending on national circumstances, these measures may include expanding opportunities for private-sector participation, introducing public auctions, supporting joint ventures, or establishing production targets and associated regulatory incentives or penalties (Annex 1 - CS 2.1.1).

In passenger transport, several mitigation options are also immediately available and could be scaled up rapidly to reduce emissions. These include expanding public transport and non-motorized transport, as well as accelerating the replacement of internal-combustion engine vehicles with electric vehicles (EVs). National analyses highlight the importance of short-term measures that improve the accessibility, reliability, safety, and overall quality of public and active transport systems in order to encourage modal shifts towards lower-carbon mobility options. The transition to EVs similarly depends on targeted support measures, including reducing upfront purchase costs, expanding charging infrastructure, and encouraging manufacturers to increase EV supply and sales (Annex 1 - CS 2.1.2).

Finally, Land Use, Land-Use Change and Forestry (LULUCF) action should prioritize halting deforestation and forest degradation while rapidly scaling up proven measures—such as improved forest management, restoration, and sustainable agriculture—that deliver immediate emissions reductions and protect livelihoods (see section 3.2.2) (Annex 1 - CS 2.1.3).

### 3.3.2 Enabling long-term emission reductions

Although rapid emission reductions are essential to place countries on a credible path towards carbon neutrality, focusing only on short-term mitigation outcomes risks overlooking the importance of actions that create the conditions for deeper structural transformations over time. Due to systemic inertia, their impact on emissions may not materialize immediately, but they are critical to achieving substantial reductions in the long term. Analysis of national pathways to net zero shows that achieving carbon neutrality requires immediate action to build conditions consistent with long-term structural changes in all sectors.

Inertia in infrastructure is a major constraint. Infrastructure systems have long lifetimes, require significant upfront investments, and shape future development pathways. Importantly, they define the potential for long-term emissions reductions. In the power sector, for instance, reducing reliance on fossil-fuel generation and scaling up renewable electricity requires major investments in transmission and distribution networks that are suited to the characteristics of renewable energy systems, including their geographical dispersion and intermittency, as well as to emerging uses such as distributed generation, storage, and electric vehicles. Planning and deploying these infrastructure investments in the short term is therefore essential to support the large-scale expansion of renewable energy over the coming decades. Moreover, short-term decisions regarding current power-plant investments are critical, as they can create long-term carbon lock-in given the long lifetime of fossil-fuel-based production capacities (Annex 1 - CS 2.2.1).

Inertia in governance and institutions is another major constraint. The freight transport sector provides a clear example, with country analyses pointing to the need for a gradual transition away from heavy dependence on diesel road freight towards increased use of rail, inland waterways, and coastal shipping. Achieving this shift requires not only investments in supporting infrastructure, but also targeted policy and institutional reforms adapted to national circumstances in order to address governance barriers and enable the transition to alternative freight systems (Annex 1 - CS 2.2.2). Lastly, country analyses also point to the slow pace of lifestyle and Behavioural change as a major challenge for the long-term diffusion of low-energy and low-carbon solutions. Transformations in consumption habits and social practices cannot occur instantly, as they depend on gradual shifts in social norms, cultural

expectations, and everyday routines. India's Lifestyle for Environment (LiFE) initiative provides an example of this approach by encouraging more sustainable consumption patterns, including greater reliance on seasonal and locally sourced food, increased use of public transport, and more moderate household energy consumption. Initiating these changes early is important to reduce future pressure on energy demand and support longer-term decarbonization objectives (Annex 1 - CS 2.2.3).

### 3.3.3 Accompanying structural economic and industrial shifts

The assessment of national pathways to net zero indicates that the transition to carbon neutrality will involve profound changes in economic structures, as carbon-intensive activities decline and new low-carbon industries expand to provide the technologies, products, and services required in a decarbonized economy. These transformations are expected to reshape patterns of employment, industrial production, investment, and international trade across multiple sectors. In the absence of appropriate policy responses, they may also generate significant macroeconomic pressures, particularly in economies that remain strongly dependent on fossil fuels or other carbon-intensive exports. Potential risks include trade imbalances, industrial decline, and employment losses in affected sectors. At the same time, new forms of dependency may emerge if countries lack domestic capacity in strategic low-carbon technologies or access to critical minerals and associated value chains.

At the same time, the transition towards a carbon-neutral global economy may also create opportunities for countries to reshape their industrial structures in ways that support both economic development and decarbonization objectives (Annex 1 - CS 2.3.1). Capturing these potential benefits—while limiting the economic risks associated with the transition—will often require proactive policies capable of steering investment towards low-carbon industrial development. The sectors involved will differ according to national priorities and comparative advantages, and may include critical mineral value chains, solar photovoltaic manufacturing and other renewable energy industries, chemicals, or iron and steel production. To support these transformations and guide industrial investment, governments can deploy a range of policy instruments adapted to domestic circumstances, including public procurement policies with local-content provisions, subsidies, concessional financing, import restrictions, or targeted tariffs (Annex 1 - CS 2.3.2).

### 3.3.4 Managing the socio-economic transition.

National pathways to net zero also highlight a range of socio-economic challenges associated with the transition, many of which are linked to rising costs that can affect the affordability of essential services such as energy and transport when accessible alternatives are not yet available. Although price increases can occur independently of climate policies, ambitious mitigation measures may intensify these pressures if the transition is not carefully managed, particularly in the energy sector. These effects tend to disproportionately impact low-income and vulnerable populations, who are more exposed to fluctuations in living costs and face greater risks of losing access to essential services. For example, the large-scale deployment of renewable energy systems may generate additional short-term costs that can contribute to higher energy bills for low- and middle-income households.

Addressing these challenges requires integrated policy approaches that combine climate mitigation measures with broader social and economic support mechanisms in order to ensure that the transition remains fair, inclusive, and socially sustainable. The design of these measures must reflect national circumstances and domestic socio-economic realities. Such approaches are especially important in the short term, when ambitious mitigation actions needed to initiate large-scale low-carbon transitions may generate significant social and economic pressures if accompanying support measures are absent. This includes recycling revenues through transfers or tax reforms and rapidly expanding affordable low-carbon alternatives—such as accessible public transport—to meet basic needs during the transition (Annex 1 - CS 2.4.1).

## 3.4 An assessment of national climate action over the last decade

This section assesses national policies implemented over the last decade, specifically since the adoption of the Paris Agreement, against the recommendations discussed in Section 3.3, by drawing on an analysis of 21 countries<sup>7</sup> with diverse economic and political contexts (DDP, 2025).

### 3.4.1 Is national action effectively supporting immediate emission reductions?

Over the past decade, significant emission reductions in power generation, passenger transport, and land use have been enabled by regulatory and economic policies that accelerated the diffusion of energy-efficient and low-carbon solutions. Key economic policies include subsidies to support adoption by end-users, such as for electric vehicles or heat pumps; increased taxes or carbon pricing to discourage fossil-fuel use; regulated auctions or tenders, sometimes combined with feed-in tariffs or feed-in

premiums, to support wind and photovoltaic deployment; and direct public investment (Annex 1 - CS 3.1.1).

However, these measures have frequently faced obstacles in practice. In some countries, a lack of political continuity and sustained support for climate transitions has led to policy interruptions. In others, political fragmentation and polarization have eroded backing for specific policies, leading to their dilution or even dismantling. Delays in implementation have also been experienced due to insufficient consensus and communication. In many cases, policies have also been introduced in a scattered or partial manner: some measures incentivized low-carbon technologies while others discouraged fossil-fuel use, but without the complementary actions needed to form coherent packages capable of fully shifting investment and behaviour (Annex 1 - CS 3.1.2).

Finally, key strategic policy frameworks have been adopted for the land-use sector, particularly in countries where it

<sup>7</sup> Argentina, Brazil, Canada, China, Côte d'Ivoire, Costa Rica, Dominican Republic, European Union, France, Germany, Guatemala, India, Indonesia, Japan, Kazakhstan, Mexico, Nigeria, Senegal, South Africa, Thailand, United States

represents a large share of national emissions, given the critical role of natural carbon sinks in short-term mitigation. These frameworks set out objectives such as forest protection or afforestation and reforestation targets, and in some cases have recently introduced initial economic measures and land tenure reforms to ensure progress. However, the effective implementation of policies is often hindered by entrenched local interests and by the absence of complementary measures, such as financial support for ecosystem services or resources for enforcement (Annex 1 - CS 3.1.3).

### **3.4.2 Is national action effectively addressing structural inertias to enable long-term emission reductions?**

Over the past decade, national policies have largely triggered the rapid development of new low-carbon technologies and the reduction of their cost, establishing some of the key technical conditions for long-term deep emission reductions. National policies have played a central role in enabling this technological progress by combining targeted public-private funding for research and development, organizing large-scale demonstration and pilot projects, and aligning expectations and reducing uncertainties for private actors by setting clear time horizons for specific technological transitions. In the power sector, for example, the rapid expansion of solar and wind technologies has resulted not only from decades of sustained research efforts, but also from a broader policy framework combining long-term renewable targets, stable support schemes, de-risking mechanisms for private investment, and public support for grid expansion and system integration. By providing revenue visibility and reducing regulatory uncertainty, this comprehensive policy mix has accelerated deployment, strengthened global supply chains, and driven steep cost declines (Annex 1 - CS 3.2.1).

However, national action has paid little attention to directing investment towards long-lived infrastructure, which is essential for achieving very low emission levels in the long run. Delays in planning and investment in the power network have slowed the development of critical long-lived infrastructure. For example, electricity grids remain insufficiently robust and flexible to integrate high shares of intermittent power sources. Public policies have supported the growth of renewables, helping the levelized cost of energy for solar and wind fall sharply, and facilitating energy access in remote areas, even in insular geographies. However, insufficient interconnection has been a major obstacle to accelerating clean energy deployment (Annex 1 - CS 3.2.2).

Finally, incentives to influence collective lifestyles and Behaviours, and to prepare for their evolution over the long term, have received very little attention in concrete policy action to date, despite their structural impact on future emissions. Values and norms that shape these Behaviours can be influenced by targeted national policies such as information campaigns, advertising obligations, educational measures, or other regulatory and economic incentives. Very few policies in the past decade explicitly targeted long-term collective behaviour to foster modern societies less dependent on energy and resource consumption, and have often worked against Behavioural shifts compatible with low-carbon societies (Annex 1 - CS 3.2.3).

### **3.4.3 Is national action consistent with the anticipation of shifts in economic and industrial strategies in the context of the global transition to net zero?**

There is growing recognition of the need to better align climate and industrial transitions. This is reflected in a rising number of strategic industrial visions and sectoral plans that explicitly incorporate the shift to a low-carbon economy. A common strategy observed in large economies is to develop the domestic manufacture of low-emission technologies and critical materials for their own transitions, recognizing the potential to create new local economic activities, jobs, and skills, while reducing dependence on imports. Another strategy consists of developing export-oriented industries in these areas, positioning countries in future global value chains. In trade-exposed economies, industrial adjustments are often driven by shifts in international competition. For example, as value chains and goods progressively decarbonize, countries have an incentive to adopt proactive national measures to reduce the carbon content of light manufacturing industries, with the objective of maintaining or gaining international market share (Annex 1 - CS 3.3.1).

New carbon-pricing mechanisms are being introduced, taxonomies are being developed to classify economic activities according to their alignment with net-zero and broader environmental goals, and local-content requirements are being adopted. Depending on national circumstances and the availability of natural resources, some countries have also introduced preferential trade tariffs to import raw critical minerals to limit dependencies on final products or export/import bans to protect national natural resources. In other situations, trade agreements can be complemented with measures to drive sustainable

industrialization and development, which consist of defining sustainability rules for accessing the domestic markets, such as criteria relating to eco-design and circularity of products, their impact on deforestation, or their carbon content. New forms of trade and financial agreements with low-carbon provisions are also emerging (Annex 1 - CS 3.3.2)

Nevertheless, in many countries, the integration between climate and industrial agendas has not materialized in tangible climate-industrial strategies despite emerging convergence in political discourse. While measures have been adopted to attract investment in key national industries compatible with climate goals, climate policies are still often perceived as conflicting with national priorities such as competitiveness and employment, which can slow progress. In countries where fossil-fuel industries have underpinned the economy for decades, public finances often depend heavily on fossil revenues. This both creates short-term pressures and requires the industrial transition to address a complex structural issue requiring economic diversification. In regions highly dependent on carbon-intensive industrial ecosystems, workforce transition risks can also generate tensions that may slow progress if reskilling, upskilling, and the creation of new economic activities are not properly anticipated. Existing fossil-fuel subsidies persist in many sectors, slowing the transition to renewables and complicating economic diversification. International finance raises further questions and challenges in recipient countries, particularly around the risks of foreign influence over national priorities or the debt burdens created by loan-based support (Annex 1 - CS 3.3.3).

#### **3.4.4 Is national action adapted to support equitable transition?**

Experiences over the past decade illustrate the consequences of climate policies designed without sufficient attention to social concerns. For example, measures such as carbon pricing, low-emission zone regulations, or undifferentiated subsidies for low-carbon technologies, which affect all households equally, can create a risk of increasing inequalities and provoking social pushback against the transition. On the other hand, other policies, such as those driving the transition in the building sector towards more energy-efficient and low-carbon

buildings, can cause an increase in rental and sale prices. Finally, in some cases, the absence or withdrawal of social public policies related to the most vulnerable can slow down the transition or significantly accelerate the deterioration of their income and quality of life. Therefore, recognition of the close links between climate policy and social priorities has grown in the years following the Paris Agreement, alongside widespread acknowledgement that well-designed climate policies should support more equitable transitions (Annex 1 - CS 3.4.1).

In some countries, building clear political bridges between climate and socio-economic agendas has helped overcome barriers and secure ambitious climate policy packages by framing climate action as a national security imperative and linking it to health, social, and economic co-benefits. This strategic convergence has given rise to initial economic policies and measures aimed at managing, or even reducing, inequalities and poverty through the climate transition. For example, in the case of carbon taxes, which are difficult to differentiate socially, revenues can be an instrument to support social objectives through adequate redistribution to support the most vulnerable households and offset the impact on their budgets. Many other economic instruments, such as subsidies, taxes, and loans, can be socially differentiated to improve the affordability of zero-emission technologies and energy-efficiency solutions while moderating potential impacts on household budgets and helping to reduce inequalities and poverty. Another approach is to increase investment in solutions that primarily benefit low-income groups, such as the energy-efficient renovation of social housing or the strengthening of public transport to provide more frequent, reliable, comfortable, and affordable services (Annex 1 - CS 3.4.2).

While solutions exist to make the climate transition socially acceptable and supportive of reducing poverty and inequalities, convergence and integration remain largely at an early stage and incomplete. In many countries, concerns about the social impacts of the climate transition—particularly the risk of increasing inequalities and poverty—has triggered resistance and, in some cases, slowed or reduced climate ambition. Progress in aligning social, economic, and climate objectives remains limited, making this one of the most pressing challenges ahead (Annex 1 - CS 3.4.3).

## 3.5 Conclusion

The analysis of national net-zero pathways helps identify key lessons to guide countries in the design of relevant action towards carbon neutrality. It stresses the need for comprehensive policy packages, anchored in the specificities of each sector and supported by international cooperation, to simultaneously address multiple objectives in a consistent policy framework. These detailed policy insights provide concrete benchmarks against which countries' progress towards carbon neutrality can be assessed. As such, this analysis can help identify priorities for strengthening national climate action (Waisman et al, 2026).

This assessment of the last decade of national climate action shows that too little proactive action has been taken to prepare for the longer-term evolution of infrastructure and Behaviours needed to reach carbon neutrality. Furthermore, despite growing recognition of the close links

between climate and social priorities, and the need to articulate climate policies with industrial, trade, and other socio-economic policies, the emergence of coherent policy packages that integrate climate, industrial, social, and economic objectives is still largely limited.

These two critical gaps highlight the necessity to anchor the design of policy at a national level in a robust, evidence-based, and widely accepted national strategy, which can provide guidance for short-term decisions within the broad context of sustained longer-term economic development. Sectoral and economy-wide policies would indeed benefit from being guided by targeted yet adaptable strategies and roadmaps, to ensure that policy actions are defined according to a clear vision of the technological and investment transitions they should trigger. The carbon-neutrality transition therefore requires the establishment of innovative governance that organizes inclusive processes supported by strong mandates, explicitly framed by a long-term perspective and informed by country-driven scientific evidence.

# 4.

## A Review of Net-Zero Assessments at a Sectoral Level: Delivering Fossil-Fuel Phase-Out in the Power Sector



### 4.1 Introduction

The power sector is one of the most important sectors for achieving deep decarbonization in the overall economy. In 2023, the electricity sector generated CO<sub>2</sub> emissions of 15.3 billion tCO<sub>2</sub> and accounted for approximately 44 per cent of overall CO<sub>2</sub> emissions from global energy use (IEA, 2025). In the net-zero scenario, the share of electricity in final energy increases from 21 per cent in 2024 to 55 per cent by 2050 (IEA, 2025), driven by surging demand from digital technologies and the increasing electrification of end-use in the building, transport, and industrial sectors. Beyond its central role in emissions reduction, the transformation of the power sector also depends critically on governance arrangements, including regulatory frameworks, planning institutions, and coordination mechanisms across sectors and levels of government.

According to the International Energy Agency (IEA) Net Zero Roadmap 2023 (IEA, 2023), achieving a 1.5°C-aligned pathway requires annual clean-energy investment to surge from approximately USD 1.8 trillion in 2023 to USD 4.5 trillion by the early 2030s. Beyond the financial requirements, the physical supply chain for deep decarbonization introduces a new era of “material-intensive” energy security. The shift towards electrification has triggered an unprecedented demand for critical minerals such as lithium, copper, and rare earth elements. As of 2025, the IEA reports that lithium demand has grown by nearly 30 per cent annually, yet the supply chain remains highly concentrated. The global imperatives of climate stabilization and industrial modernization have positioned the power sector at the nexus of national security and economic prosperity.

Eighty countries<sup>8</sup> submitted their LT-LEDS strategies by the end of 2025, and around 56 per cent of countries<sup>9</sup> have indicated a net-zero target either for GHG emissions or CO<sub>2</sub> emissions within their LT-LEDS. As highlighted in Chapter 2, however, the level of detail and institutional grounding of these LT-LEDS varies significantly, which directly affects the credibility and implementability of power sector decarbonization pathways. Since the goals are economy-wide, it is not necessary for the power sector

to be completely decarbonized, but in all cases, a deep decarbonization of the power sector has been proposed. In this chapter, these net-zero assessments are used for analysis, since the power sector forms a part of the assessment in all cases. It should be noted that not all LT-LEDS are titled as LT-LEDS or “Net-Zero Strategies”, and some declare net-zero ambitions in the narrative text without a concise title. We have focused our analysis on 11 countries across regions (Table 4-1).

**Table 4-1:** Countries shortlisted from the UNFCCC LT-LEDS portal for analysis

Europe	Americas	Asia	Africa	Oceania
UK	Canada	Japan	South Africa	Australia
Germany	Chile	India		
Denmark	USA	China		

Source: <https://unfccc.int/process/the-paris-agreement/long-term-strategies>

The eleven countries selected for this review represent 57 per cent of global GHG emissions in 2023 (Crippa et al., 2024) and provide a deliberate cross-section of the energy landscape:

- **Pioneer legislators:** The United Kingdom, Germany, and Denmark were among the first to enshrine net-zero targets into national law.
- **Resource-rich developed economies:** The United States, Canada, and Australia possess vast landmasses for renewable deployment and critical mineral reserves.
- **Emerging transition leaders:** Chile has high renewable potential, while India and South Africa represent the “just-transition” imperative, where energy access must be balanced with decarbonization.
- **The global engine:** China is included as the world’s largest carbon emitter, responsible for 34 per cent of global energy emissions and 39 per cent of global power-sector emissions in 2024.

Finally, many of these countries have fairly detailed national plans for the power sector (Table 4-2) that focus on the short term (typically 5–10 years) and provide an operational plan for the future. These plans also align well with the NDC time horizons (2030/2035) and therefore help link the strategic long-term vision provided by LT-LEDS and net-zero strategies to the short term.

8 <https://unfccc.int/process/the-paris-agreement/long-term-strategies>

9 <https://unfccc.int/lt-leds-synthesis-report>

**Table 4-2:** National plans for the electricity sector

Country	Title	Entity / Reference
United Kingdom	Delivering a reliable decarbonized power system	Climate Change Committee (CCC, 2023)
United States of America	NREL's 100% Clean Electricity by 2035 Study	NREL (Denholm, 2022)
	On the Path to 100% Clean Electricity	US DOE (US-DoE, 2023)
Australia	2024 Integrated System Plan: For the National Electricity Market	AEMO (Australian Electricity Market Operator) (AEMO, 2024)
	Electricity and Energy Sector Plan 2025	Australian Government (DCCEEW, 2025a)
Germany	A Climate-Neutral Power System in Germany in 2035	Agora Energiewende (Pescia, 2023)
Japan	Strategic Energy Plan, February 2025	Ministry of Economy, Trade and Industry (METI, 2025)
India	National Electricity Plan (Volume I) Generation	Government of India (CEA, 2023)
	Roadmap for a Net-Zero Power Sector in Gujarat	Global Centre for Environment and Energy (GCEE) at Ahmedabad University and Council on Energy Environment and Water (CEEW) (Pathak et al., 2025)
South Africa	South Africa Renewable Energy Master Plan (2025): An inclusive industrial development plan for the renewable energy and storage value chains by 2030	Department of Electricity and Energy; Department of Trade, Industry, and Competition; Department of Science, Technology, and Innovation (DEE; DTIC; DSTI, 2025)

The chapter will cover the scope and boundaries of assessments for both LT-LEDS and national energy plans. It will then assess the scenarios and models used in the assessments. This will be followed by a synthesis of technologies for long-term decarbonization

and the technologies being included in the short term. Finally, the chapter will conclude with a review of sustainable-development impacts and the just-transition dimension in the LT-LEDS and national energy plans.

## 4.2 Scope and boundaries of assessment

### 4.2.1 Electricity imports

Electricity imports are typically excluded from decarbonization strategies because they fall outside domestic regulations and, under IPCC methodology (Scope 1), only emissions occurring within national boundaries

are counted. For example, on this basis, Canada's Clean Electricity Regulations (CER) explicitly exempt electricity imports from their emission-intensity limits, focusing on domestic performance (Energy, 2024). However, from an energy-security perspective, imports of electricity or fuels to generate electricity are an important consideration in

decarbonization strategies (Shukla, Garg, & Dhar, 2009b). For example, in Japan and the UK, fuel imports for electricity generation, such as gas, are seen as an energy-security risk; therefore, decarbonization strategies prioritize sources such as nuclear and offshore wind to decouple their economies from geopolitical shocks (CCC, 2023); (METI, 2025). On the other hand, electricity imports are considered essential for fostering regional cooperation, and there is extensive electricity trade across European countries. Similarly, India's NEP 2023 integrates significant hydro-based imports from neighbouring Nepal and Bhutan, projected to reach 5,856 MW by 2032 (CEA, 2023). This highlights the interconnected nature of power systems, where national decarbonization strategies must consider cross-border energy flows as part of broader system transformations.

### 4.2.2 Greenhouse gases covered

While most strategies focus on CO<sub>2</sub>, comprehensive plans include other GHGs such as SF<sub>6</sub> and CH<sub>4</sub>. Sulphur hexafluoride (SF<sub>6</sub>) is the most potent GHG, with a global

warming potential of 24,300 times that of CO<sub>2</sub>. It is primarily used in gas-insulated switchgear (GIS). To combat leaks, California and New York have finalized state-level bans on new SF<sub>6</sub> equipment starting in 2025. In some cases, if upstream emissions are accounted for, methane (CH<sub>4</sub>) emissions from coal mines and gas infrastructure must be included for coal- and gas-based power plants.

### 4.2.3 Integration of adaptation and resilience

Power systems are increasingly vulnerable to climate hazards such as extreme temperatures, droughts, and wind speeds. Changes in any of these variables can significantly affect electricity demand and supply. Therefore, some countries are taking these variables into account as part of their assessments. For example, Denmark's assessments focus on "windless and dim" periods during winter, highlighting that resource adequacy can be marginal during weather extremes (DEA, 2022). Similarly, Chile's Virtual Power Plant (VPP) roadmap includes island-mode operations for local grids.

## 4.3 Scenarios and models used

### 4.3.1 Scenario patterns

In the LT-LEDS for the 11 shortlisted countries, two clear patterns are visible.

- **Pattern A:** **Scenario-rich modelling assessments.** These produce quantified technology mixes, energy flows, and emissions under multiple uncertainty assumptions, often using integrated assessment models and macroeconomic models in addition to energy-system modules. Canada and the United States of America (USA) are the clearest examples in this set.
- **Pattern B:** **Target-based roadmaps and milestones.** These specify what must happen by set years (e.g., coal closures, renewable-energy percentages, and grid reforms) but do not provide information on the model used or the scenario architecture followed. Germany's update and Chile's target framework fall closer to this category, although Chile also has an explicit "baseline scenario" and a carbon-budget methodology.

### 4.3.2 Country evidence on scenarios

#### Pattern A

- **Canada:** Four net-zero illustrative scenarios are disclosed: a "current assumptions" pathway plus three alternative "enabling conditions" scenarios—high electrification, high renewable/alternative fuels (including hydrogen), and high engineered CO<sub>2</sub> removals (E&CC, n.d.). The electricity results are explicitly quantified: renewables reach ~77–86 per cent of generation in 2050 across models in the current assumptions scenario, and clean electricity (renewables + nuclear) reaches 97–100 per cent with fossil generation including CCS <3 per cent.
- **USA:** The national long-term strategy uses a twelve-scenario framework and shows multiple pathways under alternate assumptions regarding technology, carbon removals, fossil-fuel prices, population/GDP (US-DoS, 2021). The strategy ties these scenarios to the 100 per cent clean electricity by 2035 goal as a core enabler.

## Pattern B

- **Australia:** Australia's annual statement 2023 has a baseline scenario as well as a scenario with additional measures. Both scenarios aim to achieve net zero by 2050 but also include short-term targets; for example, the baseline scenario incorporates the national renewable-energy targets of 82 per cent by 2030 (AG, 2023).
- **Chile:** The LT-LEDS emphasizes a carbon-budget approach with a defined methodology for allocating sectoral carbon budgets from the national NDC baseline scenario, explicitly referencing the "baseline scenario" used for 2020–2030 tracking (GdC, n.d.). Its energy sector includes explicit 2025/2030/2050 targets for generation mix and coal power plant closure trajectories.
- **Denmark:** The Climate Programme 2020 includes baseline projections and policy measures instead of presenting multiple scenarios. Nevertheless, it includes quantitative targets such as 100 per cent green power by 2027 and the use of fossil fuels only for peak loads (DMCEU, 2020)
- **Germany:** The Climate Action Plan (2016) (BMUB, 2016) and the update submitted in 2021 (BMUB, n.d.) are milestone-style documents and define relevant power-sector milestones, e.g. more than 80 per cent renewables in 2030 gross electricity consumption or coal phase-out by 2030 instead of multiple scenario-based analyses.
- **Japan and India:** Both LT-LEDS documents are predominantly strategic/qualitative. Japan explicitly states it will promote renewables as major power sources by 2050, manage grid constraints, and pursue options such as hydrogen/ammonia generation and thermal generation with CCUS, but it does not present scenarios (GoJ, 2021). India's LT-LEDS structures the electricity transition as a "strategic transition" aligned with development, innovation, and long-term net zero (2070), without any description of power-sector scenarios or model (MoEF&CC, 2022).
- **South Africa:** The LT-LEDS references reports that include mitigation analysis; however, these reports do not cover such scenarios. The electricity-transition section anchors short-term additions and system evolution as provided in the Integrated Resource Plan (2019) and references the need for detailed studies on gas-supply options and RE penetration for a just and feasible transformation (Anonymous, 2020).
- **China:** China's LT-LEDS provides milestones aligned with five-year planning-periods e.g., controlling coal growth

during 2021–2025 and reducing coal use during 2026–2030, but no scenarios or model-based analyses are mentioned (Anonymous, 2021)

### 4.3.3 Scenarios in sectoral plans

The sectoral energy plans were studied for a few countries (Australia, USA, India, and South Africa) for which LT-LEDS were analyzed. In some cases, they align very well with the long-term strategies and also Analyse scenarios, e.g., Australia's sector plan is positioned as a pathway to 2035 and beyond and has a net-zero scenario (DCCEEW, 2025b).

### 4.3.4 Models used for assessment

In the assessments, we have included models used for long-term low-emission development strategies (LT-LEDS), as well as models used for power-sector analysis, which have a more short-term operational focus.

#### a. Models for LT-LEDS and long-term decarbonization at a national level

These tools focus on economy-wide interactions and generally have time horizons of 30–50 years. The data needed includes population growth, GDP trajectories, and technology learning rates.

- **TIMES (Canada, China, UK, South Africa):** A multi-sectoral optimization model for the entire energy chain. South Africa uses **SATIM** to endogenously shape demand based on GDP and population growth.
- **LEAP (Canada, Chile, India):** The Low Emissions Analysis Platform is used for cross-sectoral GHG accounting. Chile couples it with **NEMO** for least-cost planning.
- **E3ME (Japan):** A macro-econometric model integrated with Future Technology Transformation (FTT) sub-models to evaluate economic effects on industry.

#### b. Operational models (sectoral plans)

- These tools focus on grid stability and 5–10-year investment windows. The **data needed** includes hourly load profiles, station heat rates, ramping constraints, and bus-level connectivity. **ReEDS (USA):** Uses 134 load-balancing areas and 356 resource regions to determine the type and regional location of development.

- **PLEXOS (UK, India, South Africa, Australia):** A chronological production-cost model used to simulate unit commitment and dispatch at 30-minute intervals.
- **ORDENA (India):** A mixed-integer linear optimization programme used for 8,760 hourly dispatch models with Monte-Carlo reliability indices.
- **Balmorel (Denmark):** An open-source model optimized for electricity and district-heating seasonal dynamics.
- **PyPSA-DE (Germany):** A high-resolution model for sector coupling and transmission-grid planning.

**Table 4-3:** Comparative table on scenarios and models

Country	Scenario coverage in official assessment	Model(s)/method(s) disclosed
<b>UK</b>	Delivery pathway to clean power by 2030 (technology capacity ranges to 2035 referenced in annexes)	Plan/technical annex references external system operator scenarios in connection planning annex
<b>Germany</b>	Milestones: renewable energy share, coal phase-out, hydrogen replacing gas	Policy milestone method (acts/programmes)
<b>Denmark</b>	Baseline projections and policy programme; 100% green power by 2027 expectation	Baseline projections + policy measures; discussion of CCS funding pool
<b>Canada</b>	Four illustrative net-zero scenarios	GCAM, EC-IAM, EC-MSMR (CGE)
<b>Chile</b>	Baseline scenario carbon budget allocation; energy targets to 2025/2030/2050	Carbon-budget methodology; stakeholder process
<b>USA</b>	Twelve scenarios; multiple uncertainty sensitivities	GCAM + OP-NEMS; scenario-to-model table
<b>Japan</b>	Roadmap-style strategy; no explicit scenario ensemble found	Qualitative strategy with technology pillars (renewables, nuclear, hydrogen/ammonia, CCUS)
<b>India</b>	Strategy pillars; limited model/scenario disclosure	Qualitative transitions; R&D focus
<b>South Africa</b>	Electricity transition anchored in IRP (2019) additions; calls for further studies	Integrated resource planning approach; referenced studies
<b>Australia</b>	Baseline vs additional-measures projections; sector plan to 2035	National reporting + sector plan
<b>China</b>	Planning-period milestones; system integration concepts	Five-Year-Plan style + LT-LEDS milestones

These differences in modelling approaches also reflect institutional capacities and governance traditions, with countries possessing stronger analytical capacities tending to develop more detailed scenario-based assessments.

## 4.4 Technologies for achieving net zero in the power sector

### 4.4.1 Long-term technology choices from a review of LT-LEDS

LT-LEDS documents typically define the technologies needed to achieve net zero or GHG neutrality by a defined year. These technology needs are generally defined through target shares of technologies (either capacity or generation). On the other hand, in some cases, the sequence of the phase-out for fossil technologies and the construction of infrastructure for the grid and storage are also indicated. The key technologies identified are described below. Consistent with Chapter 2, these technologies should not be viewed in isolation but as components of an integrated system transformation involving infrastructure, demand patterns, and sector coupling.

- **Renewables (wind/solar/hydro):** All 11 countries indicate renewable energy as the backbone of the power sector transformation, but they differ in scale and speed of the transition depending on resource endowments and policy choices. For example, Chile targets 80 per cent renewables in power generation by 2030 and 100 per cent renewable energy for power generation by 2050, coupled with coal power plant closures (GdC, n.d.). Denmark expects 100 per cent green power in electricity consumption by 2027, implying a rapid completion of the electricity transition ahead of other sectors (DMCEU, 2020). Canada's modelled net-zero pathways show renewable energy dominating electricity generation, with clean electricity approaching 97–100 per cent by 2050 (DMCEU, 2020). The USA similarly shows renewable energy rising substantially across 2050 pathways while unabated fossil-fuel generation declines (US-DoS, 2021).
- **Grid and transmission:** In conventional power systems, the location of power plants was driven by both demand and sources of primary energy (Shukla, Dhar, Victor, & Jackson, 2009a). However, as the role of renewable energy increases, the location of generation capacity depends increasingly on resource availability. Therefore, enhancing grid and transmission capacity is essential for linking demand to supply. The USA strategy explicitly links the scale-up of renewables to investment in grid infrastructure and increased interregional coordination to ensure resilient power systems (US-DoS, 2021). Australia similarly frames transmission expansion as essential

for connecting renewable resources and meeting its renewable goal (AG, 2023). Japan's LT-LEDS states that maximizing renewables requires securing grid capacity and managing fluctuating output and power system constraints (GoJ, 2021).

#### Storage

Every pathway in this review implicitly or explicitly relies on “flexibility” as the system enabler that turns high levels of renewable energy into a reliable supply. This flexibility is provided by storage; however, storage is also differentiated into short-, medium-, and long-duration storage.

- **Short-duration (intra-day):** batteries, demand response, and digital control for fast balancing (US-DoS, 2021).
- **Medium duration (multi-day/firming):** pumped storage, longer-duration batteries, thermal storage; some strategies explicitly mention pumped storage (India) (MoEF&CC, 2022) or molten-salt thermal storage (China) (Anonymous, 2021).
- **Long-duration/seasonal:** hydrogen-to-power or other clean fuels produced using clean electricity can also provide fairly long-duration storage.

It must be noted that LT-LEDS are not explicit about storage needs or the costs involved, as these are materially shaped by transmission expansion and renewable siting (Yamujala et al., 2025). Storage plays a critical role in ensuring balance between renewable generation and demand across sectors, particularly as electricity demand increases in transport and industry.

- **Nuclear:** Nuclear is part of power-sector decarbonization and contributes to clean electricity. For example, Japan's LT-LEDS describes nuclear as a practical in-use decarbonization option alongside renewables while also emphasizing safety, back-end challenges, and rebuilding trust after Fukushima (GoJ, 2021). Canada includes nuclear as part of its clean electricity mix (E&CC, n.d.). In the case of nuclear, there is a distinct departure from the past: all eleven countries reviewed include nuclear as a strategic priority and zero-carbon technology, and even a country such as Denmark, which has excluded nuclear in the past, is debating the use of small modular

reactors (Liou, 2023) (capacity up to 300 Mwe per unit). SMR are explicitly mentioned in the strategic energy plans of all eleven countries. China already has six reactors in operation; Canada has begun construction; and the USA has awarded construction licenses.

- **Green hydrogen and Power-to-X (PtX):** Denmark's climate programme highlights PtX as a scalable option and links CO<sub>2</sub> utilization (CCU) with green-fuel production, where CO<sub>2</sub> is coupled with hydrogen (DMCEU, 2020). Japan targets up to three million tonnes of green hydrogen by 2030 to launch the domestic hydrogen market (GoJ, 2021). India's LT-LEDS includes green hydrogen as a major innovation and cites a national ambition of 5 million tonnes of green hydrogen by 2030 (MoEF&CC, 2022). China's LT-LEDS highlights R&D for low-cost renewable hydrogen production and large-scale hydrogen applications, embedded in an integrated system transition (Anonymous, 2021).

### Role of carbon-capture technologies

CCS is not generally recommended in the power sector, but is mostly considered for mitigating emissions from hard-to-abate sectors. For example, Canada's scenarios show fossil generation (including CCS) becoming very small by 2050, at less than three per cent in the "current assumptions" scenario, and CO<sub>2</sub> removals (including BECCS) are used to offset residual emissions from hard-to-abate sectors (E&CC, n.d.). Australia and Germany have a similar approach and position CCUS as potentially helpful for hard-to-abate sectors (AG, 2023), (BMUB, n.d.). However, India's LT-LEDS anticipates heavy reliance on CCS due to significant coal capacities and therefore considers it essential for meeting net-zero by 2070 (MoEF&CC, 2022). Similar to India, South Africa's LT-LEDS includes CCS for coal power, steel, cement, and coal gasification (Anonymous, 2020). Japan's LT-LEDS includes plans for CCS-network optimization (hubs and clusters), liquefied CO<sub>2</sub> shipping, and storage-site assessment for the societal implementation of CCS (GoJ, 2021).

Peer-reviewed literature shows that CCS is a crucial mitigation option in some modelled contexts, but its role depends strongly on broader system constraints and sector-coupling assumptions (Vinca, Rottoli, Marangoni, & Tavoni, 2018). European modelling work similarly highlights that CCS deployment feasibility and scale depend on scenario design and infrastructure constraints (Holz et al., 2021). CCS can increase the levelized cost of electricity (LCOE) for both coal- and gas-based plants. For example,

for natural gas plants with CCS, the increase in LCOE can be between 70–100 per cent above the base case (natural gas plants without CCS). To offset this increase, a carbon tax of US\$110–160 per tonne of CO<sub>2</sub> would be needed (Hayat, Hasan, & Elshurafa, 2024).

Overall, CCS plays a complementary and context-specific role in the power sector, rather than a central pillar of decarbonization strategies, unless more reliable and cost-effective CCS technologies are developed.

### 4.4.2 Short-term choices from sectoral plans

The technology choices in short-term plans (5–10 years) align well with the long-term visions of LT-LEDS; however, the focus is on more mature technology options, such as renewable deployment and related infrastructure (expand grid capacity and storage) to ensure that additional flexibility and reliability are maintained during fossil-fuel phase out and growth in electrification. This reflects a "least-regrets" approach, prioritizing mature technologies that can deliver immediate emission reductions while preparing for deeper structural changes.

- **UK:** The Clean Power Action Plan defines clean power as ≥95 per cent clean generation by 2030, explicitly allowing for a residual role for unabated gas as a security mechanism (CCC, 2023). This is noteworthy because it formalizes a system-planning compromise that recognizes the practical challenge of eliminating all fossil-fuel generation on an hourly adequacy basis by 2030 (Yamujala et al., 2025).
- **Canada:** The Clean Electricity Regulations establish a regulatory regime to prevent excessive CO<sub>2</sub> emissions from fossil-fuel electricity generation, with the government explaining that "beginning in 2035" the regulations set limits on CO<sub>2</sub> pollution from almost all fossil units, while allowing compliance flexibilities and not prescribing specific technologies (Government of Canada, n.d.). This is an example of a short-term instrument that sets a clear end-state goal while leaving provinces/territories flexibility over the technology mix.
- **Australia:** Australia's near-term plan focuses on meeting the 82 per cent renewable-energy objective by 2030, with explicit emphasis on (a) building transmission, (b) scaling storage (including a national Capacity Investment Scheme expansion that signals support for nine GW of

dispatchable capacity and 23 GW of variable renewable energy generation), and (c) improving social license and community engagement for network infrastructure (DCCEE, 2025a).

- **USA:** The NREL 2035 study provides a detailed set of short-term scenarios to indicate feasibility trade-offs and “least-regrets” options. The national strategy also quantifies the scale of the challenge—specifically, the new generation, transmission, and storage capacity needed to maintain reliability and enable economy-wide electrification.
- **India:** India’s official summary of the National Electricity Plan indicates substantial increases in the share of non-fossil capacity by 2026–27 and further increases by 2031–32 (CEA, 2023).
- **South Africa:** The LT-LEDS identifies short-term additions to the generation mix (through IRP-anchored numbers) including new wind and PV builds to 2030, as well as additional hydro, concentrated solar power (CSP), and other generation types, highlighting the near-term build programme and the logic of replacing decommissioned capacity (Anonymous, 2020). The Renewable Energy Masterplan complements this by focusing on industrialization and value-chain development for renewables and storage (DEE;DTIC;DSTI, 2025).
- **Scale and pace of deployment:** The USA strategy explicitly notes the ambition of sustaining high rates of deployment of new technologies through mid-century, including annual capacity additions and storage growth (US-DoS, 2021). Canada’s modelling similarly reflects very large increases in electricity generation under electrification scenarios (E&CC, n.d.).
- **Supply chains and workforce skills:** The UK Clean Power documentation includes a skills-evidence annex, reflecting the recognition that workforce availability can constrain build-out rates (UK-Gov, 2024). Australia’s annual statement similarly points to skills shortages and the need for reskilling as part of the transition (AG, 2023). Peer-reviewed synthesis work finds mixed employment outcomes across electricity transitions and emphasizes the importance of policy design for equitable outcomes (Das & Patil, 2025).
- **Energy security and import dependence:** Japan explicitly frames renewable expansion and efficiency as reducing the value of fossil fuel imports, while also noting constraints on renewable deployment (cost, land, coexistence with the environment) (GoJ, 2021). India’s LT-LEDS highlights that higher dependence on renewables can create new import dependencies (equipment and material supply chains), raising energy-security concerns (MoEF&CC, 2022).
- **Governance and planning consistency:** Chile’s LT-LEDS and power-sector decarbonization planning emphasize institutional tools, sectoral carbon budgets, and long-term policy coherence; South Africa’s experience underscores the importance of integrated resource planning and regular updates under changing system conditions (Anonymous, 2020).

#### 4.4.3 Implementation challenges and barriers

Despite differences in technology preferences, several barriers cut across countries, and these are listed below.

- **Transmission and siting/social license:** Australia explicitly highlights that meeting renewable-energy targets requires major transmission investment, community engagement, and fit-for-purpose approval processes (AG, 2023). The USA similarly highlights transmission and siting challenges, as well as the need for new infrastructure and storage to maintain reliability (US-DoS, 2021).

These challenges underscore the importance of institutional coordination mechanisms, long-term planning mandates, and regulatory stability, as discussed in Chapter 1, which are critical to aligning short-term decisions with long-term decarbonization pathways.

## 4.5 Coverage of sustainable development impacts and just-transition dimensions

### 4.5.1 Jobs and skills

Jobs are the most frequently mentioned sustainable-development dimension across the LT-LEDS and power-sector plans, but they are often discussed in qualitative terms. They are framed as a socio-political necessity and affect entire regions (e.g., coal regions), where livelihoods depend significantly not only on direct jobs but also on indirect employment. The USA strategy explicitly links transmission and generation investment to job growth and highlights workforce training as an enabling factor (US-DoS, 2021). Australia's statement discusses reskilling from emissions-intensive occupations to clean-energy jobs and notes skills shortages as a constraint (AG, 2023). Chile's LT-LEDS explicitly frames the energy transition as a driver of sustainable development and job creation, and includes SDG-linked sections, including "Decent Work and Economic Growth." (GdC, n.d.) South Africa's LT-LEDS includes a specific focus area on ensuring a just transition with jobs for all (Anonymous, 2020).

Employment effects vary by phase and job type. For example, renewable capacity-building tends to generate construction and manufacturing jobs, while the phase-down of fossil-fuel capacity results in a decline in operation and maintenance jobs; therefore, policy attention is needed to address the distributional outcomes (Das & Patil, 2025). In Chile, the impacts of the coal phase-out on employment illustrated the need for regionally targeted measures (Feng, Song, Viteri, Liu, & Vogt-Schilb, 2023). This confirms that employment impacts are not automatic outcomes of the transition but depend on policy design and Labour-market strategies.

### 4.5.2 Local environment, air quality, and health

Direct air-quality framing is more prominent in some LT-LEDS strategies than in others; however, decarbonizing coal and reducing fossil-fuel combustion are widely associated with improved local environmental outcomes. Australia frames ageing coal power plants as increasingly unreliable and projects their replacement with renewable energy and storage to deliver cleaner energy (AG, 2023). In the US, a 100

per cent clean grid by 2035 is projected to save 130,000 lives and avoid \$400 billion in health costs (Denholm, 2022).

### 4.5.3 Water savings and water risks

Water is a comparatively less discussed dimension in most national power-sector net-zero strategies, and there is limited quantitative data to support its analysis. It is often discussed in broader adaptation and water-security contexts. Chile's report contains extensive analysis of water-security governance and explicitly discusses progress towards water security under different climate-change scenarios (GdC, n.d.). Australia's annual statement includes water-management adaptation measures and National Water Grid funding (AG, 2023). Water considerations become increasingly important in power-sector planning, particularly in regions dependent on thermal generation or hydropower.

In the peer-reviewed literature, however, quantitative analyses show that power-sector water consumption can decline dramatically under certain technology pathways, although results depend on the generation mix and technology choices (Lohrmann, Farfan, Caldera, Lohrmann, & Breyer, 2019). Other peer-reviewed work highlights that water impacts depend on the cooling systems used in coal- and gas-based power generation, and that some low-carbon options (such as hydropower and bioenergy) can be water-intensive, so decarbonization does not always result in water savings (Xu, Tan, Yao, & Lv, 2024).

### 4.5.4 Just transitions

The just-transition dimension aims to ensure that the transition towards decarbonization happens in a fair way, leaving no one behind. A transition to renewables is bound to create opportunities in that sector, but the phase-down of fossil fuels is also certain to result in adverse effects. This dimension has been addressed in a few country reports but not in all. In South Africa, the idea is to promote social dialogue between government and Labour, as well as to expand the renewable-energy and storage activities, which have so far been confined to businesses and middle- and

high-income households, to transition hotspots such as the Mpumalanga coalfields (DEE; DTIC; DSTI, 2025). Germany's Coal Commission is managing the impact on workers through social protection and retraining. Discussions on

protecting households from rising heating costs (BMUB, n.d.) are also taking place. The just-transition dimension remains unevenly integrated across national strategies, indicating a gap between policy recognition and implementation.

## 4.6 Conclusion

In summary, the analysis demonstrates that achieving fossil-fuel phase-out in the power sector depends not only on technology deployment but also on coordinated system transformation, supported by robust governance frameworks, consistent policy signals, and sustained investment in infrastructure and institutional capacity.

The transition to a net-zero power sector has shifted from theoretical feasibility to industrial and logistical execution. Successful national frameworks, as observed across the eleven countries in this review, are characterized by the close alignment of long-term LT-LEDS visions with decadal legal mandates and operational grid planning. The emerging “S+3E” framework in Japan and the “orderly transition” phases in Australia demonstrate that decarbonization is increasingly viewed as a prerequisite for national security and economic productivity rather than as a competing interest [7, 7].

The technological pathways identified emphasize a tiered approach: short-term deployment of firmed renewables and

grid modernization, followed by long-term reliance on SMRs, hydrogen, and CCS for hard-to-abate segments. However, the economic viability of CCS remains a strategic pivot point, contingent on significant carbon pricing or subsidy regimes to offset its 80 per cent LCOE premium in the coal sector. Additionally, the massive build-out of infrastructure required—tripling renewable capacity and transmission miles—faces universal barriers in permitting timelines, supply chain concentration for critical minerals, and the fragility of social license.

Finally, the report underscores that the technical transition must be a “Just Transition.” Success in nations such as South Africa and India is fundamentally linked to the “social contract”—ensuring that workers in legacy coal hubs are actively reskilled for the green economy. As nations compete for clean energy manufacturing dominance, the 2025–2035 window will define the winners of the new global energy economy. decarbonizing the power sector is no longer just a climate imperative; it is the cornerstone of 21st-century industrial modernization and global prosperity.

# 5.

## A Review of City-Level Net-Zero Plans



### 5.1 Introduction: The urban imperative in the global climate architecture

Historically, climate action has centred on national government commitments. However, the focus is shifting to cities, which are increasingly becoming central actors in addressing climate change. Although cities occupy less than two per cent of the Earth's land area, they consume 78 per cent of global energy and generate over 60 per cent of greenhouse gas emissions (Liu et al., 2024). Approximately 56 per cent of the global population resides in urban areas as of 2024 (UNDESA, 2024). Consequently, urban development will play a decisive role in determining the success of global efforts to limit warming (Satterthwaite, 2008); UNDP, 2024).

Cities are also disproportionately vulnerable to climate impacts, including urban extreme heat, flooding, and sea-level rise. Furthermore, urban energy consumption is a major source of air pollution, which poses immediate public health risks. These dual pressures—as both major emitters and frontline victims of climate change—further

underscore the imperative for ambitious city-level climate action. Consequently, cities face distinct challenges: while they lack authority over national energy grids or tax policy, they do have regulatory control over the buildings, waste management, and transport sectors, which have significant emissions impacts.

This chapter reviews global city strategies for achieving net-zero emissions and analyses city climate plans across eight dimensions: emissions coverage, adaptation planning, scenario modelling approaches, analytical tools, technology priorities, accounting for fuels such as hydrogen, measurement of co-benefits including health improvements, investment requirements, and alignment with national objectives. It should be noted that the definition of 'net zero' varies across cities. Some cities account solely for direct emissions, whereas others include emissions from the consumption of goods. Reliance on carbon offsets also

differs significantly among cities. To anchor this analysis, it is useful to report on the main dimensions along which net zero definitions vary: (i) boundary type—territorial versus consumption-based accounting; (ii) greenhouse-gas scope—CO<sub>2</sub> only versus all GHGs, including CH<sub>4</sub> and N<sub>2</sub>O; (iii) the role of offsets—ranging from offset-reliant to absolute-reduction targets; and (iv) target year—most commonly 2050, but with some cities targeting 2030 or 2040. A standardized and systematic definition of ‘net zero’ at the city level is missing, and defining one would greatly improve comparability across plans and enhance accountability.

It is important to distinguish city-level net-zero plans from national Long-Term Low Emission Development Strategies (LT-LEDS) submitted under the Paris Agreement. While LT-LEDS set the national trajectory towards mid-century

climate goals, city net-zero plans translate these ambitions into locally actionable strategies tailored to urban contexts. City plans often address sectors and emission sources with greater specificity than national strategies and may set more ambitious timelines. However, the success of city-level plans frequently depends on alignment with national policy frameworks, particularly regarding grid decarbonization and fiscal transfers.

The following cities are discussed in this chapter: Copenhagen, London, New York, Los Angeles, Vancouver, Mumbai, Jakarta, Lagos, Bogotá, São Paulo, Nairobi, Accra, Cape Town, Johannesburg, Shenzhen, Seoul, Mexico City, and Buenos Aires. A comprehensive summary table of these cities, their plans, target years, and key sectors is presented in Table 5-1.

**Table 5-1:** Overview of city-level net-zero plans

City	Country	Plan Name	Target Year	Key Sectors	Methodology /Tools	GHG Scope	Adaptation Integrated
Copenhagen	Denmark	CPH 2025 Climate Plan / KKB2025 Klimaplanen	2025 (carbon neutral)	Energy, buildings, transport, city administration	Custom bottom-up model	CO <sub>2</sub> (territorial)	Limited
London	United Kingdom	Net Zero 2030 Target Analysis (Element Energy/GLA)	2030 / 2050	Buildings, transport, energy supply, waste	Custom stock-turnover model (Element Energy)	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O (Scopes 1, 2; consumption-based satellite)	Partial (flooding, heat)
New York City	United States	Pathways to Carbon-Neutral NYC / Local Law 97	2050	Buildings (~70%), transport, waste, energy	Custom stock-turnover + hourly load modelling	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O (Scopes 1 & 2)	Yes (flooding, heat)
Los Angeles	United States	LA Green New Deal	2050 (carbon neutral)	Transport, buildings, energy, waste, water	Sectoral target-setting framework	CO <sub>2</sub> (Scopes 1 & 2)	Yes (extreme heat, wildfire)
Vancouver	Canada	Climate Emergency Action Plan (CEAP)	2050 (before)	Buildings (incl. embodied carbon), transport, waste	Sectoral targets with embodied carbon module	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O (Scopes 1, 2, 3 for embodied)	Yes (sea-level rise, heat)

City	Country	Plan Name	Target Year	Key Sectors	Methodology /Tools	GHG Scope	Adaptation Integrated
Seoul	South Korea	2050 Carbon Neutrality Roadmap / Green New Deal	2050	Buildings, transport, industry, energy	National-city integrated modelling	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O (Scopes 1 & 2)	Partial
Shenzhen	China	Carbon Peaking & Neutrality Action Plan	Peak by 2030 / carbon neutral by 2060	Buildings, industry, transport, energy	LEAP-SD model	CO <sub>2</sub> (Scopes 1 & 2)	Limited
Mumbai	India	Mumbai Climate Action Plan (MCAP)	Net zero by 2050	Buildings, transport, waste, energy, water	WRI India / GPC-based inventory	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O (Scopes 1 & 2)	Yes (flooding, heat, vulnerability mapping)
Jakarta	Indonesia	Jakarta Climate Resilient Development Strategy	2050 (aligned with national NDC)	Transport, waste, energy, buildings	NEXSTEP / GPC-based	CO <sub>2</sub> , CH <sub>4</sub> (Scopes 1 & 2)	Yes (flooding, sea-level rise)
Lagos	Nigeria	Lagos Climate Action Plan	2050 (aspirational)	Waste, transport, energy, buildings	Downscaled national data / EIE proxies	CO <sub>2</sub> , CH <sub>4</sub> (Scopes 1 & 2)	Yes (flooding, erosion)
Nairobi	Kenya	Nairobi City County Climate Action Plan	2050	Waste (primary), transport, energy	GPC + national downscaling	CO <sub>2</sub> , CH <sub>4</sub> (Scopes 1 & 2)	Yes (drought, flooding)
Bogotá	Colombia	Climate Action Plan (CAP) 2020–2050	2050 (carbon neutral)	Transport (48%), buildings, waste, energy	Sectoral modelling with BRT electrification scenarios	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O (Scopes 1 & 2)	Yes (flooding, landslides)
São Paulo	Brazil	PlanClima SP	2050	Transport, buildings, waste, energy, land use	CURB Pathways module (C40/ World Bank)	CO <sub>2</sub> , CH <sub>4</sub> (Scopes 1 & 2)	Partial
Mexico City	Mexico	Programa de Acción Climática / Vision Zero	2050	Transport, buildings, energy, waste	Sectoral + air quality modelling (PM <sub>2.5</sub> , black carbon)	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O, black carbon	Yes (air quality, heat, water)
Cape Town	South Africa	Cape Town Energy2040 / Climate Change Strategy	2050 (aspirational)	Energy, buildings, transport, water-energy nexus	LEAP model	CO <sub>2</sub> , CH <sub>4</sub> (Scopes 1 & 2)	Yes (drought, water resilience)

City	Country	Plan Name	Target Year	Key Sectors	Methodology /Tools	GHG Scope	Adaptation Integrated
Johannesburg	South Africa	Climate Action Plan / Joburg 2040 GDS	2050	Energy, transport, buildings, waste, industry	CURB tool (C40 pilot)	CO <sub>2</sub> , CH <sub>4</sub> (Scopes 1 & 2)	Partial
Accra	Ghana	Greater Accra Resilient & Integrated Development Plan	Aligned with national NDC	Waste, transport, energy	National downscaling / GPC	CO <sub>2</sub> , CH <sub>4</sub> (Scopes 1 & 2)	Yes (flooding, coastal erosion)
Buenos Aires	Argentina	Plan de Acción Climática	2050 (carbon neutral)	Transport, buildings, waste, energy	CURB tool (C40 pilot)	CO <sub>2</sub> , CH <sub>4</sub> (Scopes 1 & 2)	Partial
Rajkot	India	Net-Zero Transport Strategy	2050 (transport sector)	Transport	CCAT + LEAP (UNEP-CCC)	CO <sub>2</sub> (transport Scopes 1 & 2)	Limited
Kumasi	Ghana	Net-Zero Transport Strategy	2050 (transport sector)	Transport	CCAT + LEAP (UNEP-CCC)	CO <sub>2</sub> (transport Scopes 1 & 2)	Limited

A central theme that emerges across the cities is the tension between technically feasible solutions identified through modelling and what cities can realistically finance, govern, and implement. The sections that follow examine these issues systematically—beginning with how cities define the scope and boundaries of their net-zero assessments (Section 5.2), the scenarios they construct to navigate uncertainty (Section 5.3), the analytical tools and models

they deploy (Section 5.4), and the technology pathways they prioritize (Section 5.5). The chapter then turns to cross-cutting dimensions: accounting for secondary fuels such as hydrogen (Section 5.6), the role of co-benefits in building political support (Section 5.7), investment requirements and financing constraints (Section 5.8), and alignment with national frameworks (Section 5.9).

## 5.2 Scope and boundaries of assessments

The credibility of any net-zero claim depends on the rigour of its inventory boundary. A city's carbon footprint is a fluid concept, influenced by the movement of goods, energy, and waste across municipal boundaries (Ramaswami, Chavez, & Chertow, 2012). While adherence to the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) is becoming standard practice, significant heterogeneity

remains in how cities define the boundaries of their responsibilities, particularly regarding consumption-based emissions and the integration of adaptation metrics. In this section, we discuss the scope of the reviewed net-zero plans with regard to sectoral coverage, greenhouse gases included, emission accounting based on consumption, and the integration of adaptation and resilience,

### 5.2.1 Sectoral coverage and greenhouse gas inclusion

Most city assessments are structured according to the GPC’s “BASIC (Basic Assessment for Sector-based Inventory Compilation)” reporting level, which includes Scope 1 and Scope 2 emissions from three primary sectors: stationary energy, transport, and waste. These sectors are typically those over which municipal governments have the greatest direct control or influence. Scope 1 refers to direct emissions from sources within the city boundary. Scope 2 emissions include the indirect emissions from grid energy, specifically electricity, district heating and cooling, and steam. In addition, some key scope 3 categories are included in BASIC, such as waste, where disposal occurs outside city boundaries.

Stationary energy sources are consistently identified as the primary sources of emissions in high-density, service-oriented cities. For example, the “*Pathways to Carbon-Neutral NYC*” study finds that buildings contribute nearly 70 per cent of New York City’s greenhouse gas emissions (N. Y. C. Mayor’s Office of Sustainability, Con Edison, & National Grid, 2021) (NYC Gov., 2021a). This predominance necessitates mitigation strategies that prioritize the built environment, including detailed assessments of building-stock turnover, heating-system electrification, and improvements in thermal efficiency. Similarly, in Seoul, stationary energy is the main driver of emissions, leading to a “Green New Deal” that emphasizes the Remodelling of both public and private infrastructure to achieve the 2050 carbon-neutrality target (Agora Energiewende, 2021) (Wang & He, 2024). In these cases, the assessment scope is typically operational, focusing on electricity and fuel consumption within buildings rather than the embodied carbon in construction materials. In industrial cities such as Shenzhen or Johannesburg, manufacturing and industrial process emissions (IPPU) contribute a larger share of GHG emissions (Liu et al., 2024). Including such cities in the assessment is essential for understanding the full diversity of urban emission structures.

Transport is the dominant source of emissions in sprawling or rapidly motorizing cities. For instance, Bogotá’s Climate Action Plan (CAP) 2020–2050 attributes 48 per cent of greenhouse gas emissions to the transport sector (Alcaldía de Bogotá, 2021) (Blanco, Windisch, Perkins, Ito, & Leape, 2022) (Papaioannou & Windisch, 2022). As a result, assessments in such contexts are closely linked to urban mobility planning, with a focus on electrifying the TransMilenio Bus Rapid Transit (BRT) system and developing a metro network. In Los Angeles, the “Green New Deal” also

prioritizes transport, reflecting the city’s reliance on private vehicles and establishing a target for a fully zero-emission vehicle fleet (Carter, 2020; D. K. I. Jakarta Provincial Government, 2021). These assessments frequently include detailed analyses of vehicle-kilometres travelled (VKT) and modal-split data.

Waste accounts for a smaller share of emissions in many Global North cities but remains a primary focus for intervention in the Global South. Nairobi’s low-carbon development plan, for example, emphasizes solid-waste management (Ulpiani, Veters, & Maduta, 2023). Assessments in these contexts focus on methane (CH<sub>4</sub>) emissions from landfills, given methane’s high global-warming potential as a short-lived climate pollutant. By prioritizing methane capture from waste, cities such as Nairobi and Jakarta integrate climate mitigation with pressing public-health and sanitation objectives, thereby broadening the definition of climate action to encompass essential municipal services (C40 Cities, 2025; D. K. I. Jakarta Provincial Government, 2021).

Advanced city assessments now typically include multiple greenhouse gases rather than focusing solely on CO<sub>2</sub>. Mumbai’s Climate Action Plan (MCAP), for example, tracks a comprehensive inventory that includes carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) (Brihanmumbai Municipal Corporation & W. R. I. India, 2022; PreventionWeb, 2022). This broader scope is particularly important for cities with substantial waste or industrial sectors. Earlier city targets often addressed only CO<sub>2</sub>, which may have led to underestimating the climate impacts of waste management and wastewater treatment. The terminology used in targets—such as “carbon neutral,” “net zero,” or “fossil-fuel free”—often reflects differences in gas coverage, with “net zero” increasingly denoting a comprehensive greenhouse-gas scope consistent with the IPCC definition.

### 5.2.2 Consumption-based emissions

A notable advancement in city-level assessments involves addressing Scope 3 emissions, which are embedded in goods, services, food, and construction materials consumed by urban residents but produced beyond city boundaries. Historically, city inventories have focused on production-based emissions (Scopes 1 and 2), thereby shifting emissions linked to urban consumption to manufacturing regions. Leading cities are now seeking to address this “carbon loophole.”

London exemplifies this expanded approach. Although its primary “Net Zero 2030” target is based on territorial emissions to comply with national reporting standards, the Greater London Authority (GLA) recognizes that a consumption-based inventory would result in an emissions profile nearly twice that of the territorial account (GLA, 2022a). The city has established dedicated initiatives to quantify and mitigate these consumption emissions, particularly in the food and textiles sectors, acknowledging that genuine global sustainability necessitates addressing urban resource demand (Net Zero Go, 2022).

Vancouver’s Climate Emergency Action Plan (CEAP) explicitly incorporates embodied carbon into its primary targets. “Big Move 5” establishes a goal to reduce embodied emissions from new buildings and construction projects by 40 per cent by 2030, relative to a 2018 baseline (City of Vancouver, 2020a). This broadens the assessment boundary from building operations (such as heating and cooling) to include the manufacturing of materials including concrete, steel, and glass. This methodological change necessitates that cities engage with supply chains beyond their jurisdiction, influencing procurement standards and building codes to promote transformation within the construction industry (City of Vancouver, 2024; Trinh, Eadon-Clarke, & O’Callahan, 2021).

In contrast, cities in developing economies such as Lagos and Accra typically limit their primary assessment scope to Scope 1 and Scope 2 emissions. This limitation is often due to data constraints, as developing a consumption-based inventory requires advanced input-output economic models that may not be available at the municipal level in data-scarce contexts (Odu-Onikosi, Oke, Hopke, & Solomon, 2025; Olawoyin, 2018). In these cities, the primary focus remains on managing direct emissions from rapid industrialization and urbanization, rather than on addressing consumption patterns (KPMG, 2022).

### 5.2.3 Integration of adaptation and resilience

A distinguishing characteristic of recent city assessments is the comprehensive integration of adaptation and resilience within the net-zero framework, which contrasts with many

national strategies. In urban contexts, climate change poses immediate physical challenges, including flooding, heatwaves, and storms. Consequently, these assessments often incorporate detailed vulnerability mapping alongside emission inventories.

Mumbai serves as a prominent example of this integrated methodology. The Mumbai Climate Action Plan (MCAP) is based on a comprehensive “Climate and Air Pollution Risks and Vulnerability Assessment” that spatially maps risks at the ward level. This assessment indicates that over 35 per cent of Mumbai’s population resides in flood-prone areas, with informal settlements identified as zones of “differential vulnerability” due to inadequate housing and limited services (The Migration Story, 2025). By incorporating social vulnerability, the assessment ensures that mitigation measures, such as mangrove preservation or drainage improvements, are recognized for both their carbon-sequestration potential and their ability to protect the city from extreme weather events (Bhattacharjee, Sharma, & Tiwari, 2025).

Cape Town similarly expands its assessment scope to include a “hazard, vulnerability, and risk” analysis. The city’s experience with the “Day Zero” drought has led to the integration of water resilience into energy planning. The assessment models the interdependence between water and energy systems, recognizing that future desalination plants, while adaptive, would significantly increase electricity demand and thus present a mitigation challenge (City of Cape Town, n.d.; GreenCape, 2022). This systems-based approach enables the identification of trade-offs and synergies that would be missed in a narrowly focused mitigation assessment.

Mexico City also demonstrates this integrated approach through its “Vision Zero” strategy, which combines transport decarbonization with road safety and air-quality resilience. The assessment includes monitoring black carbon, thereby directly linking climate action to reductions in respiratory illness and immediate improvements in quality of life (CDMX, 2025). This comprehensive scope is essential for maintaining political and public support for climate action in cities where immediate health and survival concerns may outweigh long-term carbon objectives.

## 5.3 Scenarios covered in assessments

City-level assessments use scenario planning to manage the substantial uncertainties inherent in long-term transitions. These scenarios serve as the narrative foundation for climate action plans, enabling policymakers to assess the resilience of different strategies across varying technological, economic, and social contexts. This review identifies a common typology of scenarios employed by global cities: the business-as-usual (BAU) baseline, the planned policy trajectory, and several net-zero or ‘ambitious’ pathways.

### 5.3.1 Business-as-usual (BAU) baselines

The business-as-usual (BAU) scenario serves as the counterfactual reference point, projecting the city’s emissions in the absence of new climate interventions. The trajectory of the BAU scenario differs markedly between cities in the Global North and those in the Global South.

In mature, post-industrial cities such as New York and London, the BAU scenario often shows a gradual decline or stabilization of emissions. This is driven by the gradual decarbonization of the national electricity grid and slow but steady improvements in vehicle efficiency mandated by national standards. For example, London’s baseline scenarios incorporate the UK government’s existing commitments to phase out coal power, meaning the city inherits a decarbonizing baseline before it takes any specific local action (GLA, 2022a).

Conversely, rapidly developing cities such as Shenzhen, Jakarta, and Johannesburg present BAU scenarios marked by significant emissions growth. Shenzhen’s assessment, utilizing LEAP-SD models, indicates that under a BAU trajectory driven by continued industrial expansion and population growth, emissions from the building sector may not peak by 2030 (IDEAS REPEC, 2024). Similarly, Jakarta’s BAU scenario forecasts a significant increase in emissions due to increased vehicle ownership and reliance on a coal-based electricity grid (ESCAP & NEXSTEP, 2021). In these settings, the net-zero pathway signifies not just an acceleration of emissions reduction but a fundamental decoupling of development from emissions.

### 5.3.2 Divergent pathways to net zero

The most advanced assessments do not present a single route to net zero; instead, they model multiple pathways to explore the full range of possible solutions. London’s “Analysis of a Net Zero 2030 Target” by Element Energy is particularly notable for its detailed articulation of four distinct scenarios, each reflecting a different transition philosophy (GLA, 2022b). Despite this diversity, the reviewed pathways can be grouped into four broad typologies:

- **High Electrification:** This scenario relies on the rapid development and widespread adoption of heat pumps and electric vehicles (EVs). It assumes that the electricity grid will be reinforced in time to accommodate the substantial increase in demand resulting from the electrification of heating and transport (e.g., London’s High Electrification, NYC’s Electrification pathway). While this pathway achieves notable emissions reductions (27 per cent residual emissions by 2030), it is associated with high capital costs and significant logistical challenges, particularly in retrofitting London’s ageing building stock.
- **Diversified:** A hybrid scenario that balances electrification with strategic hydrogen use (e.g., NYC’s Diversified, London’s Accelerated Green). It keeps options open by maintaining a blended gas grid (biomethane and hydrogen) while pushing for electrification in transport and easy-to-retrofit buildings.
- **Constrained:** A governance-constrained pathway, where the ceiling of ambition is set not by technology but by the regulatory and fiscal powers available to the city (e.g., Cape Town’s Limited Mandate scenario).
- **No Constraints:** This theoretical “maximum ambition” scenario disregards existing policy and economic limitations to achieve the lowest possible residual emissions. It necessitates the early retirement of gas boilers and vehicles, underscoring the scale of interventions needed to achieve absolute zero emissions within a short period.

This typology reveals that the divergence across cities is driven as much by governance structures and national policy contexts as by technology choices.

New York City’s *Pathways to Carbon-Neutral NYC* study adopts a comparable tripartite structure, modelling an “Electrification” pathway, a “Low-Carbon Fuels” pathway (utilizing renewable natural gas and hydrogen), and a “Diversified” pathway (BioCycle, 2021). The assessment concludes that the “Diversified” pathway provides the greatest resilience, as it reduces risks associated with grid failure, slow adoption of heat pumps, and limited availability of renewable fuels by not relying exclusively on electrification.

Cape Town’s scenario planning introduces a critical governance dimension. Its modelling contrasts a “Green Economy” scenario (high ambition) with an

“Ambition Under Limited Mandate”. This case illustrates a structural governance constraint: without national grid decarbonization, a city’s net-zero claim risks being aspirational rather than possibly technically achievable, highlighting the danger of cities setting targets they lack the legal or structural power to meet” scenario (City of Cape Town, n.d.). The latter reflects the political reality faced by many cities, modelling the maximum emissions reduction achievable if the national government does not decarbonize the electricity grid or permit municipal power procurement. This scenario demonstrates a reduction of only approximately 50 per cent by 2050, underscoring that for Cape Town, achieving net zero is legally unattainable without national regulatory reform.

## 5.4 Models and methods used for assessment

The effectiveness of urban strategies depends on the computational models used to simulate city systems. This review identifies a spectrum of methodological approaches, ranging from standardized tools offered by city networks to custom stock-turnover models developed by specialist consultancies. The spectrum of models used is described below.

The Long-range Energy Alternatives Planning (LEAP) system is widely adopted, especially in cities that require detailed modelling of energy, economic, and environmental interactions. Cape Town employed LEAP to develop its energy scenarios. The model enabled simulation of energy demand across the residential, transport, and industrial sectors under multiple policy assumptions, including a solar water-heater rollout. LEAP’s adaptability to data limitations facilitated the exploration of scenarios comparing national grid intensity with local renewable procurement (Borchers & Lewis, 2012; UCT, 2005). Shenzhen applied a specialized LEAP-SD model to integrate socio-economic drivers with building energy consumption. This allowed for dynamic simulation of how variations in population density, per capita floor area, and industrial structure affect the timing of the city’s carbon peak (Du et al., 2024; IDEAS REPEC, 2024).

Within the C40 network, the Climate Action for Urban Sustainability (CURB) tool serves as a primary methodological instrument. Developed in collaboration with the World Bank, CURB is intended to address data gaps in

urban contexts. São Paulo used the CURB Pathways module to calibrate its “Ambitious Scenario” for the PlanClima SP (Krizek & Santos, 2024). The tool provided proxy data where local information was missing, enabling the city to estimate the emissions impacts of specific actions, such as 100 per cent electrification of the bus fleet and municipal building retrofits. This standardized approach facilitates comparability between C40 cities (C40 Cities, 2017a; Prefeitura de São Paulo, 2020). Johannesburg and Buenos Aires have also piloted CURB to prioritize infrastructure investments, using its scenario-planning capabilities to visualize the emissions wedge of different policy interventions (C40 Cities, 2017a).

Cities with greater financial capacity often commission custom-built models that offer higher granularity than standardized tools. London engaged Element Energy to build a bespoke bottom-up stock model. Unlike top-down macroeconomic models, this approach simulates the physical turnover of millions of individual assets—boilers, cars, vans—based on their lifespans and consumer adoption rates. This allowed London to define precise deployment rates (e.g., number of heat pumps installed per week) required to meet the 2030 target (ERM, 2018; Muñoz Mateos, 2023). New York City utilized a similar stock-turnover approach for its buildings sector analysis to support Local Law 97. This was integrated with hourly electricity load modelling to assess the “winter peaking” risk—the danger that widespread electrification of heat could spike electricity demand on cold days beyond the grid’s capacity (Li, 2024; NYC Gov., n.d.).

The City Climate Analysis Tool (CCAT), developed by the UNEP Copenhagen Climate Centre, was used to assess city net-zero transport strategies for the cities of Rajkot, in India, and Kumasi, in Ghana, along with the LEAP model. CCAT (formally known as City Transport Transparency Tool) is a modular land-use–transport integration tool that enables cities to model trip generation, mode choice, vehicle fleet composition, and resulting emissions under different policy scenarios at the traffic-analysis-zone level.

A persistent challenge identified in the review is the data disparity between cities in the Global North and the Global South. While London can model individual boiler replacements, cities such as Lagos and Nairobi often rely on downscaled national statistics or per-capita proxies from global datasets, such as Google’s Environmental Insights

Explorer (EIE) (Ratledge, 2023). The *Synthesis of Long-term Strategies* document observes that 2030 milestones in developing city plans are frequently approximate or qualitative (e.g., “expand BRT”) rather than precise quantitative targets (e.g., “reduce transport emissions by 34.5 per cent”), reflecting these underlying data limitations. A concern is that reliance on high-level proxies and global datasets in developing cities may lead to misallocated climate investments. For instance, focusing resources on electric vehicle adoption in cities where mass transit or informal paratransit are the backbone of urban mobility may divert limited capital from more impactful interventions, such as expanding and improving public transport systems. Context-specific data and locally calibrated models are essential to ensure that climate actions are both efficient and equitable.

## 5.5 Key technologies identified for net zero

Achieving net zero necessitates a fundamental technological transformation of urban infrastructure. While the specific technology mix varies by climate and development status, most city assessments are structured around a core triad: energy efficiency, electrification, and a decarbonized energy supply, across sectors such as buildings and transport.

Beyond buildings and transport, two important sectors warrant additional discussion. First, waste management is identified as a key mitigation measure in several city plans, particularly in the Global South. Cities such as Nairobi and Jakarta prioritize methane capture from landfills, composting, and circular-economy approaches as cost-effective emission-reduction strategies with significant co-benefits for public health and sanitation. Second, non-motorized transport (NMT) and walking infrastructure feature prominently in many plans. Cities including Bogotá (ciclovías network), several Indian cities (NMT masterplans), and European cities (the 15-minute city concept) are investing in pedestrian and cycling infrastructure as low-cost, high-impact interventions that simultaneously reduce emissions and improve urban liveability. These additional sectors, while often contributing smaller shares of total urban emissions, can offer significant co-benefits and are increasingly being integrated into comprehensive city climate strategies.

In regions where heating demand is predominant, decarbonizing heat constitutes the most significant technological challenge. Heat Pumps: London’s “High Electrification” scenario identifies the air-source heat pump as the critical technology for replacing natural-gas boilers, aiming for over two million installations by 2030. This technology is Favoured for its high efficiency (coefficient of performance) but faces barriers in the city’s older, thermally inefficient housing stock (GLA, 2022a; Zils, Einarsson, & Hopkinson, 2024). District Heating: Cities with a history of communal energy systems, such as Copenhagen, Stockholm, and Seoul, rely heavily on district-heating networks (Johansen, 2022). Stockholm aims to achieve a fossil-fuel-free status by 2040 by switching these networks to bio-oil and waste-heat recovery. Copenhagen’s strategy has heavily utilized biomass (wood pellets) to replace coal in its Combined Heat and Power (CHP) plants—a technological choice that has enabled rapid carbon reductions but is now facing scrutiny regarding ecosystem impacts and supply chain sustainability. It is worth reflecting, however, on whether simply substituting fossil carbon with biogenic carbon constitutes a genuine net-zero strategy. Large-scale bioenergy deployment raises concerns about land-use competition, biodiversity loss, water consumption, and lifecycle emissions that may offset the intended climate benefits. Cities relying heavily on biomass pathways should

critically assess whether such strategies deliver net-positive environmental outcomes or merely shift the carbon burden geographically and temporally (Zheng et al., 2022). Energy Efficiency: Deep retrofitting, or “fabric efficiency,” is considered a universal prerequisite. Analysis from New York City indicates that, without reducing building energy demand by approximately 50 per cent through envelope improvements, the electricity grid would be unable to support the load from electrified heating (Chen et al., 2022; NYC Gov., 2021a).

However, in tropical and hot-arid cities—such as Mumbai, Jakarta, Lagos, and many Middle Eastern and Southeast Asian cities—cooling rather than heating constitutes the dominant energy challenge (Alabsi, 2025). Strategies for these contexts include district-cooling systems, passive building design, cool roofs and pavements, urban greening, and stringent efficiency standards for air conditioning. India’s National Cooling Action Plan provides a framework that several Indian cities are adapting to their local conditions (MoEF&CC, 2019).

Across the cities reviewed, a clear pattern of convergence and divergence emerges. Most cities converge on

electrification and energy efficiency as the primary levers for decarbonization, particularly in buildings and transport. However, cities diverge sharply on the role of hydrogen, biomass, and nature-based solutions, reflecting differences in resource endowments, industrial structure, and national policy contexts.

Electric Vehicles (EVs): For private transport, EVs are widely recognized as the leading technological solution. Shenzhen has achieved full electrification of its public bus and taxi fleets, establishing a global benchmark (Gabriel & Galvão). Los Angeles has set a target for 100 per cent zero-emission vehicles by 2050, supported by an extensive rollout of charging infrastructure (Carter, 2020; Totah, 2022). Electric Mass Transit: In the Global South, where private car ownership is relatively low, the technological focus is on high-capacity public transport. Bogotá is expanding its TransMilenio BRT system with electric buses, while Jakarta is transitioning its TransJakarta fleet. The primary intervention extends beyond vehicle technology to system integration, establishing a multimodal network that replaces informal, high-emission paratransit (C40 Cities, 2025; Climate Chance, 2021).

## 5.6 Accounting for emissions from secondary fuels

City-level accounting for secondary fuels—specifically electricity and hydrogen—is a complex technical domain in which methodologies can significantly alter the perceived progress towards net zero. Since cities are rarely energy islands, they must account for the emissions embodied in the energy they import.

Most cities calculate Scope 2 emissions (indirect emissions from purchased electricity) based on the carbon intensity of the regional or national grid. Sensitivity to National Action: London and New York’s assessments reveal a high sensitivity to grid decarbonization. London’s ability to reach its 2030 target relies on the UK grid decarbonizing rapidly; if the national grid achieves net zero by 2035, London’s residual emissions fall by over 1 MtCO<sub>2</sub>e. The assessments typically use national government projections (e.g., UK HMT Green Book) to forecast these emission factors (GLA, 2022a). The “Limited Mandate” Trap: Cape Town’s assessment highlights the vulnerability

of this accounting method. With 64 per cent of the city’s emissions stemming from electricity supplied by a national utility (Eskom) that is heavily coal-dependent, the city’s Scope 2 emissions remain stubbornly high regardless of local efficiency measures (van der Merwe, 2018). This structural constraint forces the city to push for regulatory changes to allow for “Independent Power Producers” (IPPs) and local renewable procurement, effectively trying to “clean” its own portion of the grid (UCT, 2005). Market-Based Accounting: Some cities, notably Copenhagen, use market-based accounting to balance their books. Copenhagen counts the renewable energy it produces or invests in, such as offshore wind, as a credit against its consumption. This allows the city to claim “carbon neutrality” even if it still emits CO<sub>2</sub> from other sources, as long as its renewable exports mathematically offset its residual emissions. This approach is transparent but distinct from “absolute zero” and relies on the city acting as an energy trader (City of Copenhagen, 2012).

Hydrogen accounting remains an emerging challenge in city planning. NYC’s “Pathways” study provides a sophisticated critique of hydrogen accounting. It notes that while hydrogen emits no carbon at the point of use, “blue hydrogen” (produced from natural gas with carbon capture) can have significant upstream methane leakage and production emissions. The study warns that without rigorous lifecycle accounting, switching to blue hydrogen could inadvertently increase net GHG emissions compared to direct electrification (NYSERDA, 2022). London’s analysis differentiates supply by scenario. In the “High Hydrogen” scenario, it assumes a specific mix of blue and green hydrogen availability. However, it conservatively estimates that before 2030, hydrogen supply will be limited to “large anchor demands” (industry, transport depots) supplied via

dedicated pipelines or road tankers, rather than a ubiquitous utility network (Element Energy, 2022).

Consequently, most city assessments adopt a cautious approach to hydrogen, considering it a solution for specific hard-to-abate sectors rather than as a primary fuel. London’s assessment is explicit that widespread hydrogen heating for buildings is not a viable technology option before 2030 due to the infrastructure requirements of converting the gas grid. Instead, hydrogen is earmarked for heavy goods vehicles (HGVs) and industrial clusters (GLA, 2022a). Seoul, aligning with South Korea’s national industrial strategy, is more bullish, envisioning a “hydrogen city” with fuel cell applications in power generation and transport (Agora Energiewende, 2021).

## 5.7 Sustainable development impacts

An overarching observation is that cities are strategically deploying a co-benefits framing to reframe the political economy of climate action. Rather than presenting decarbonization as a cost or sacrifice, leading cities use co-benefits—improved public health, economic recovery and job creation, as well as just-transition outcomes—to build broad-based political coalitions for ambitious climate plans. The following examples from health, economic recovery, and a just transition illustrate this strategic approach across different urban contexts. City climate action is now recognized as a comprehensive development strategy rather than solely an environmental responsibility. Assessments systematically quantify net-zero co-benefits to build political support and justify major capital investments.

In many cities, especially in the Global South and congested capitals, air quality is the primary driver of climate action. Mexico City, New Delhi, and Bogotá explicitly link their transport decarbonization strategies to public-health outcomes. Mexico City’s climate programme integrates with “Vision Zero” to quantify the reduction in particulate matter (PM<sub>2.5</sub>) and black carbon, translating these reductions into avoided hospitalizations and mortality statistics (CDMX, 2025). London frames its net-zero pathway as an extension of its Ultra Low Emission Zone (ULEZ) success. The assessment quantifies the health benefits of reduced NO<sub>x</sub> and PM emissions, positioning the £75 billion climate investment as a public-health intervention that saves the NHS money (GLA, 2022b). In the post-COVID era, net zero is increasingly viewed as

an economic recovery strategy. Seoul’s Green New Deal is explicitly an economic strategy, aiming to invest 45 trillion KRW to create jobs in green retrofitting and digital infrastructure. The assessment measures success not just in tonnes of carbon, but in employment figures (Agora Energiewende, 2021). Vancouver’s CEAP includes an “Economic Benefits” indicator framework that tracks the growth of the green-building sector. By mandating low-carbon materials and high-efficiency retrofits, the city aims to stimulate a local “green economy” market, estimating significant job growth in skilled trades (City of Vancouver, 2020b). Copenhagen has long positioned its climate plan as a “Green Growth” engine, arguing that its transition has proven the possibility of decoupling GDP growth from carbon emissions, thereby attracting cleantech investment (City of Copenhagen, 2012).

The concept of a “Just Transition” is becoming increasingly central to assessment methodologies. New York City conducts distributional analyses to ensure that the costs of building mandates (LL97) do not result in rent increases for low-income tenants and that investments in clean air are prioritized in “environmental justice communities” (Boehm et al., 2022). Cape Town addresses “Energy Poverty,” recognizing that for many residents, access and affordability are the primary energy challenges. Its assessment prioritizes interventions such as ceiling retrofits in low-income housing, which provide both carbon savings and immediate improvements in thermal comfort and health for disadvantaged populations (City of Cape Town, n.d.).

## 5.8 Investment needed for implementation

A review of net-zero strategies in major global cities, C40 members, and a small set of EU Mission “Climate City Contracts” (see Annex 2) reveals that investment is frequently referenced. In the strategies reviewed, 80 per cent include some discussion of investment, finance, funding sources, or financial instruments. However, only 14 per cent clearly state quantified investment needs. These results are consistent with broader urban climate-finance literature: investment is widely acknowledged as a constraint, but quantified, finance-ready roadmaps remain less common (Negreiros et al., 2021).

The costs for achieving net zero are often presented in terms of capital costs, but some city assessments include operational costs (fuel, maintenance) as well. This matters because it changes the financing conversation from “who will pay this extra cost?” to “how do we steer inevitable spending into lowcarbon options and capture savings to repay capital?” (GLA, 2022c). The same logic is seen in New York City’s “Pathways” work (CPI, 2023): It explicitly notes that many modelled costs are not incremental because buildings and vehicles must be fuelled replaced, and upgraded over time as they reach the end of their useful life (NYC Gov., 2021b).

A major reason that cities are reframing investment needs is that operational savings and avoided costs strengthen the investment case. For example, the London analysis notes that the fuel costs (heat and electricity) of buildings and running transport are around £11.1 billion/year today and could fall by 44 per cent to £6.2 billion/year by 2030 through building-envelope improvements, electrification, and mode shift (Greater London Authority, 2022).

### 5.8.1 Public investment is critical

Public finance is often described as insufficient, but it plays four critical roles in making urban net zero investable: i) by creating the enabling environment for financing, ii) funding public goods, iii) de-risking private investment, and iv) making services affordable (OECD, 2023).

Financing spreads high-up-front costs over time, but revenues such as grants, taxes, user charges, property income, etc., are still needed to pay up-front costs, fund

operations and maintenance, and repay financing (OECD, 2023). Cities can therefore access financing only when they create revenue sources.

Second, many high-impact urban actions, such as public transport, are public goods or have diffuse benefits (clean air, reduced congestion), so direct private revenue streams are weak. Therefore, international development finance and public budgets remain central for urban infrastructure, and can even “bring in” private capital (Godfrey & Zhao, 2016).

Third, public institutions are often the anchor for de-risking through guarantees, viability gap support, and project-preparation grants. Recent work on scaling private finance in cities emphasizes how guarantees, co-financing, and blended structures can make municipal initiatives investable (GGGI, 2025).

Fourth, public finance is needed in many cases to keep user costs affordable for all sections of society. As such, public finances are required to provide targeted subsidies, for example for public transport, and cannot rely on project revenues alone (CPI, 2024).

However, despite the importance of public finances, a key challenge in developing countries is the limited capacity and mandate of city governments to raise resources independently. For example, in India, urban local bodies have limited autonomy to raise revenue through taxes, tariffs, etc., and, as a result, depend on state governments (Tiwari, Tirumala, Shukla, Joshi, & Upadhyay, 2023). In most developing-country contexts, central, state, or provincial governments provide the majority of public financial resources, and municipalities have constrained revenue-raising authority. Another issue is that many low- and medium-income countries have a low sovereign credit rating that makes it difficult to access debt financing. The situation may be further aggravated due to city-specific factors, which can result in a city-specific credit rating being even lower than the sovereign credit rating (Floater et al., 2017). This means that even well-designed city net-zero plans may face implementation barriers without supportive intergovernmental fiscal transfers and national enabling policies. The extent to which city governments can autonomously finance and implement climate actions remains a critical determinant of plan feasibility.

### 5.8.2 Private investment

At a global level, private actors already finance 54 per cent of mitigation flows (CPI, 2024) households/individuals (USD 185bn), corporations (USD 206bn), and commercial financial institutions (USD 244bn) each playing a significant role (CPI, 2024). For city net-zero plans, the contributions may vary, but most of it is towards building upgrades, clean appliances, EV purchases, rooftop solar installations, plus utility and infrastructure investment. Notably, at the city level, a significant share of the required investment is expected to come from the private sector—particularly for building retrofits, electric vehicle purchases, rooftop solar installations, and clean appliances. Public investment is primarily concentrated in waste management infrastructure and public transport systems. Explicitly recognizing and facilitating private-sector investment through enabling policies, incentive structures, and de-risking mechanisms is therefore essential for plan implementation. The New York City pathways make it clear that a large part of long-run spending is tied to replacement cycles, but the direction of that spending depends on policy, technology availability, and cost allocation principles (N. Y. C. Mayor’s Office of Sustainability et al., 2021). Therefore, a stable and credible policy environment is important (GGGI, 2025).

### 5.8.3 City examples

City net-zero assessments highlight a significant investment gap. Cities are moving from estimating costs to developing

financial systems that can mobilize private capital. The London report quantifies a gross capital cost of £75 billion to reach net zero by 2030. Crucially, the assessment reframes this cost by highlighting operational savings: the investment is projected to reduce citywide energy bills by £6.2 billion annually by 2030, presenting a compelling return-on-investment (ROI) argument during a cost-of-living crisis (GLA, 2022b). New York City: The “Pathways” study estimates a total societal investment of \$1.5 trillion between 2020 and 2050 to achieve carbon neutrality. The analysis clarifies that a significant portion of this is “redirected” capital—money that would have been spent on conventional systems (e.g., gas boilers, internal-combustion cars) but must now be steered towards low-carbon alternatives (NYC Gov., 2021a). In developing economies such as Johannesburg and Cape Town, the focus is on “bankability.” Municipal budgets are insufficient to fund the transition. Cape Town has successfully issued Green Bonds to fund water and energy infrastructure, a mechanism also utilized by Mexico City to finance sustainable transport (C40 Cities, 2017b, 2017a; CEMR CCRE, 2024). Mumbai has innovated by integrating a “Climate Budget” directly into its municipal finance system, allocating 32 per cent of its capital expenditure in 2024–25 to climate-relevant projects, ensuring that climate action is mainstreamed rather than sidelined as a special project (WRI, 2025a, 2025b). At the global scale, broader assessments suggest that C40 cities collectively require \$1 trillion in investment to stay on a 1.5°C trajectory, underscoring the need for international finance institutions to lend directly to subnational entities (C40 Cities, 2017a).

## 5.9 Alignment with national levels

A final critical factor is the vertical integration of city and national strategies. The review identifies three main modes of interaction:

**Top-Down Synchronization:** In China, city targets are strictly aligned with national goals. Shenzhen’s carbon peaking roadmap operates under the “1+N” policy framework, ensuring that the city’s peak (before 2030) and neutrality (2060) targets are in lockstep with national Five-Year Plans. The city’s emissions trading scheme is designed to integrate seamlessly with the national carbon market (ICAP, 2026; State Council of the People’s Republic of China, 2025).

**Bottom-Up Leadership (The Ambition Gap):** In many Western democracies, cities are acting as “ambition accelerators.” London’s 2030 net-zero target is two decades ahead of the UK’s 2050 national binding target. The city’s assessment explicitly notes that achieving this requires the city to “go it alone” in areas where national policy lags, such as implementing road pricing or stricter building standards (GLA, 2022a). Similarly, during periods of federal inaction in the US, cities such as NYC and Los Angeles maintained Paris-aligned targets that diverged sharply from national policy, effectively acting as subnational guarantors of the country’s climate commitments (WRI, 2025a).

**Structural Misalignment:** For some cities, national policy acts as a brake on ambition. Cape Town and Johannesburg are constrained by South Africa’s Integrated Resource Plan (IRP), which dictates a continued reliance on coal. Without the regulatory freedom to procure renewable energy

independently (breaking the national utility’s monopoly), city assessments show that net zero is mathematically impossible, regardless of local political will. This “Limited Mandate” scenario highlights the urgent need for regulatory reform to unlock the city’s potential (City of Cape Town, n.d.).

## 5.10 Conclusion

This assessment of city-level net-zero plans reveals that urban climate action has matured significantly, moving from symbolic declarations to rigorous, quantified, and multi-dimensional planning. Cities are deploying advanced stock-turnover models, integrating adaptation with mitigation, and innovating with financial instruments such as green bonds and climate budgets. Yet this maturation has also exposed structural fault lines that no single city can resolve on its own.

Five cross-cutting findings emerge from the review. First, cities converge on electrification and energy efficiency as foundational strategies, but diverge sharply on the role of hydrogen, biomass, and carbon offsets, reflecting differences in resource endowments, industrial structure, and national policy signals rather than disagreements about climate science. Second, a persistent and arguably widening gap exists between the ambition of city targets and the governance powers available to achieve them. Cape Town’s “Limited Mandate” scenario demonstrates that even with high local ambition, a city constrained by a coal-heavy national grid can achieve at most a 50 per cent reduction by 2050 — falling well short of net zero. Mumbai’s 2050 target similarly depends on national grid decarbonization over which the city has no jurisdiction. Third, a pronounced data and capacity asymmetry divide Global North and Global South cities: London can model individual boiler replacements, while Lagos relies on downscaled national statistics and per-capita proxies, a disparity that risks Channelling climate investment towards visible but suboptimal interventions such as electric vehicles in cities where mass transit serves the majority of trips. Fourth, the integration of adaptation and resilience is most advanced where climate hazards are already lived realities. Mumbai’s ward-level vulnerability mapping, Cape Town’s water-energy nexus planning following “Day Zero”, and Mexico City’s black carbon monitoring all emerged from direct experience of crisis rather than anticipatory planning. Fifth, the financing gap remains the single largest implementation barrier, compounded in the Global South by constrained mandates for municipal revenue-raising and dependence on central government transfers.

The fragility of even the most advanced plans warrants emphasis. Copenhagen’s acknowledgement of missing its 2025 carbon neutrality target due to the failure of a planned carbon capture and storage facility illustrates the risk of anchoring strategies to unproven technologies or contingent national funding. London’s scenario analysis reveals that reaching net zero by 2030 would require not just technological substitution but also politically demanding behavioral shifts, including a 40 per cent reduction in car travel. These are not failures of planning but reminders that net-zero pathways operate within political economies that models cannot fully capture.

Ultimately, the success of city-level strategies depends on closing what might be termed the ‘vertical gap’ between municipal ambition and national enablement. Cities can lead on building efficiency, waste diversion, and urban transport—but deep decarbonization of electricity, industry, and freight requires national governments to provide clean grids, regulatory devolution, and intergovernmental fiscal mechanisms. Future city net-zero planning would benefit from five priorities: (i) standardized definitions and reporting frameworks to enable meaningful comparison across cities; (ii) investment in locally calibrated data and modelling tools to replace the proxy-dependent approaches prevalent in the Global South; (iii) explicit governance mapping that identifies which actions lie within municipal authority and which require national or regional coordination; (iv) systematic quantification of co-benefits health, employment, and resilience to build the political coalitions necessary for sustained implementation; and (v) dedicated urban climate financing mechanisms that recognize cities as distinct fiscal entities with borrowing constraints different from those of sovereign governments.

The plans reviewed here provide the roadmap. The challenge now is the political and financial architecture required to travel it.

# Annexures

## Annex 1 Case studies list related to Deep Decarbonization Pathways

### PART 1 CASE STUDIES

For further information on these case studies (see page numbers below), refer to the DDP Report 2024, Making it happen: national pathways to net-zero. <https://ddpinitiative.org/ddp-annual-report-2024/>

#### CS 1.1.1: p27-28.

- **South Africa** – Based on cost estimates, our modelling showed that CCS will only be necessary for specific industrial uses and processes that are difficult to decarbonize.
- **Mexico** – Prioritizing CCUS for the cement industry within Mexico's industrial policy can help drive a faster and more effective adoption of CCUS compared to alternative approaches.

#### CS 1.1.2: p23.

- **Argentina** – Achieving net zero in the DDS would necessitate a significant shift from natural-gas systems in buildings to heat pumps, electric or solar water heaters, or electric cooking devices.
- **South Africa** – For industrial energy uses, many processes would need to transition to electricity to meet net zero.
- **USA** – A combination of extended federal tax credits for EVs, enhanced state-level EV sales targets and incentives, and corresponding investments in EV infrastructures could substantially increase electric car and truck sales.

#### CS 1.1.3: p23.

- **In Mexico, South Africa, and the USA**, the analysis shows that structural changes in urban and transport

organization could help moderate the increase in per capita mobility, and related energy and emissions, compared to the CPS, while continuing to meet the needs of the population.

#### CS 1.2.1: p31-32.

- **Brazil** – One key strategy is the restoration of extensive degraded pasturelands. By rehabilitating these areas for agricultural expansion, Brazil can avoid deforestation while ensuring continued growth in food production.
- **India** – The adoption of agroforestry practices on croplands is key to increase the absorption capacity of soils, while providing complementary revenues for farmers.
- **Indonesia** – The significant shift from net emissions to a net annual carbon sink is primarily driven by reductions in deforestation and forest degradation, along with the restoration of degraded peatlands and mangroves and the expansion of forested land.

#### CS 1.3.1: p34-35.

- **China** – The transition away from fossil fuels is expected to significantly reduce methane and nitrous oxide emissions from the energy sector, but non-CO<sub>2</sub> emissions from agriculture require targeted mitigation action.

#### CS 1.3.2: p35-36.

- **Nigeria** – Strategies to reduce non-CO<sub>2</sub> emissions from agriculture while simultaneously ensuring the achievement of key development goals are: precision agriculture and urban farming, improved livestock management, and integrated water resource management.

## PART 2 CASE STUDIES

For further information on these case studies (see page numbers below), refer to the DDP Report 2024, Making it happen: national pathways to net-zero. <https://ddpinitiative.org/ddp-annual-report-2024/>

### CS 2.1.1: p47-48.

- **Mexico** – Public auctions and private participation could accelerate and lower power sector costs.
- **Argentina** – While existing regulations are not applied by private companies, it requires more control and penalties, or even the creation of a public utility.

### CS 2.1.2: p49-50.

- **Mexico** – Key actions such as reallocating road space to public transport and non-motorized modes could be taken without large investments or inertias.
- **United States** – A set of federal, state-level, and city-level economic incentives and standards can boost EV adoption by 2030.

### CS 2.1.3: p52-53 with additional examples from India and Indonesia.

- **Brazil** – Implementing existing forest protection laws to stop deforestation will require additional financial and human resources to monitor and enforce laws.

### CS 2.2.1: p41-42 with additional examples from the United States.

- **China** – While the construction of new coal power plants may address short-term power and heating needs, these plants are likely to become stranded assets in the long term, complicating China's energy transition towards carbon neutrality.
- **Senegal** – The scenario following the current gas sector master plan meets the objective of universal electricity access, but could hinder the planned expansion of renewable energy as outlined in the renewable energy strategy and required to reach the climate objectives.

### CS 2.2.2: p43.

- **Nigeria** – Setting new governance and institutional rules will be required to develop rail freight and limit the dependency on road freight.

### CS 2.2.3: p44.

- **India** – Embracing Lifestyle For Environment (LiFE) to drive Behavioural changes is a necessary global movement to achieve net zero.

### CS 2.3.1: p57-61 with additional examples from the United States, Mexico, Argentina, Nigeria, and South Africa.

- **South Africa** – The localization of renewable energy components is a potential strategy to mitigate the negative impacts (e.g., job losses in the coal sector) while simultaneously enhancing the benefits of a net-zero transition in a coal dependent energy system.
- **Indonesia** – Downstreaming Indonesia's mineral industry could reduce dependence on imports of critical green technologies to meet the national demand for EV batteries and solar panels, while also generating domestic value added and creating new jobs.

### CS 2.3.2: p58-61 with additional examples from the United States.

- **South Africa** – Strategies to achieve this could include increased public procurement with local content requirements, incentives such as special economic zones and subsidies, as well as import duties on renewable energy components.

- **Indonesia** – National policy officially bans the export of raw materials and provides several facilities and incentives for local companies to create downstream mineral industries.

### CS 2.4.1: p64-66 with additional examples from Argentina.

- **Brazil** – The use of carbon market revenues for reducing Labour taxes and providing direct transfers to the most vulnerable could accelerate economic inclusivity and resilience in transitioning towards a low-carbon economy.

- **United States** – Enhanced public transit systems and additional economic incentives could lead to a lower proportion of disposable income being spent on transport.

## PART 3 CASE STUDIES

For further information on these case studies (see page numbers below), refer to the key findings and country chapters of the DDP Report 2025, A Decade of National Climate Action: Stocktake And The Road Ahead. <https://ddpinitiative.org/ddp-report-2025/>

**CS 3.1.1:** *p38 with additional examples from the United States, Kazakhstan, and Brazil.*

- **Canada** – A large final emitter carbon pricing system is still in place (despite political backlash), partly because this tool has been identified as having the most impact and least political costs to reduce emissions.
- **Nigeria** – Despite the weak fiscal and infrastructure landscape, Nigeria has started to convert its climate commitments into concrete assets, regulations, and revenue streams that will keep future emissions on a downward trend. Efforts include investments in renewable energy projects such as the 700 MW Zungeru hydropower project.
- **Japan** – Japan has introduced subsidies to encourage end users to adopt low-carbon technologies and has also implemented carbon pricing. The government plans to further strengthen its carbon pricing measures in the coming years.

**CS 3.1.2:** *p39 with additional examples from Argentina, Canada, and Germany.*

- **Mexico** – Policies supporting renewables have been put in place, but their specific design and implementation have limited their effectiveness in driving a real shift away from fossil fuels.
- **USA** – At the federal level, the alternating agendas of the last three administrations have limited the U.S.A.'s ability to deliver consistent global leadership under the Paris Agreement, while also creating challenges domestically for delivering the short-term Nationally Determined

Contribution (NDC) targets and making needed progress towards long-term net-zero goals.

**CS 3.1.3:** *p39 with additional examples from Brazil.*

- **Dominican Republic** – Attempting to ensure that the AFOLU sector remains a carbon sink through dedicated short-term measures.
- **Côte d'Ivoire** – To facilitate reforestation measures, the State has initiated the process of securing land tenure in the national territory.
- **Indonesia** – Efforts to decarbonize the land-use sector materialize through strengthened policies, community engagement, and restoration initiatives, yet stable land governance and implementation are necessary to reach the FOLU Net Sink 2030 objective.

**CS 3.2.1:** *p35 with additional examples from Brazil, China, and the United States.*

- **Germany** – Political efforts to accelerate planning and permitting procedures may already allow for increased efficiency and declining module prices, in turn helping the LCOE for photovoltaics to drop significantly. Currently, both PV and wind power have become the most cost-effective forms of electricity generation.
- **EU** – The decarbonization of Europe's passenger and freight transport sectors relies on the phase out of internal combustion engines linked to the uptake of zero or low-emission vehicles. Emission performance standards and targets have been critical in driving technological innovations and production.

**CS 3.2.2:** *p35 with additional examples from the United States, India, and South Africa.*

- **Brazil** – Renewable power production exploded, but the development of the power network and storage capacities has not been planned accordingly to accommodate a very high share of renewables (87,5 per cent)
- **Indonesia** – In order to connect dispersedly located renewable resources, enhance system reliability, and enable electricity access to rural and remote areas, public policies have been actively enabling the development of both super grids and micro grids.

**CS 3.2.3:** *p35 with additional examples from Germany.*

- **India** – Mission LiFE is an initiative which seeks to encourage a lifestyle in harmony with nature and reflect the principles of climate justice by focusing on three main changes, specifically demand, supply, and policy. It encourages 75 individual actions ranging from reducing consumption and waste to saving water and energy.
- **France** – The focus on electric vehicles has evicted the concern on the size and cost of vehicles (energy efficiency and affordability), letting the industry develop a strategy towards larger, heavier, and more expensive propositions, now a difficulty in the transition towards electrification for many reasons (just transition, resource sovereignty, and recycling, urban space, etc.).

**CS 3.3.1:** *p42 with additional examples from France, Indonesia, and Thailand.*

- **China** – Industrial policies drove the Chinese automotive industry towards electric vehicles enabling a convergence between climate and industrial goals.
- **Argentina** – The 2023 National Energy Transition Plan proposes, among others to explore different strategies for green hydrogen, and the 2024 National Strategy for the Development of the Hydrogen Economy proposes the production, use, and export of green, blue, and pink hydrogen.

**CS 3.3.2:** *p43 with additional examples from EU, Kazakhstan, Brazil, Japan, and Indonesia.*

- **India** – Customs duty has been cut on imports of raw mineral products to encourage domestic processing.
- **South Africa** – The JETP identified priority sectors beyond coal, also considering socio-economic aspects of clean electricity, new energy vehicles, and new export products such as green hydrogen and derived products. The JETP Investment Plan (JET IP) also includes a significant priority of building institutional capacity and governance structures and developing the climate knowledge needed for addressing social, technical, and other aspects of the transitions.
- **CS 3.3.3:** *p43 with additional examples from China, EU, France, Indonesia, India, Mexico, and South Africa.*
- **Brazil** – Strategic industrial policies to lead to a new Paris-Compatible Brazilian economy is under way, but

facing challenges related to competing interests in oil and gas sectors, as well as short-term financing pressure.

- **Kazakhstan** – Coal production and use receive substantial subsidies. Such measures distort energy markets, undermine the competitiveness of renewables, and weaken incentives for diversification.

**CS 3.4.1:** *p46 with additional examples from Germany and Argentina.*

- **France** – The unanticipated and unaddressed effects of carbon pricing and low-emission zone regulations on people's ability to move have proven counterproductive for the climate transition, as the *gilets jaunes* movement illustrates the political risks of neglecting mobility and distributional impacts.
- **USA** – Upgrading buildings towards zero-energy buildings may cause an increase in rental prices, thus placing a financial burden on low- and middle-income households.

**CS 3.4.2:** *p46 with additional examples from the United States and Mexico.*

- **Guatemala** – Enhancing public transit is a clear national priority to support social inclusion by providing affordable and energy-efficient mobility options for low-income populations.
- **Senegal** – The electric BRT is supporting the transition towards net zero, while representing at the same time an important policy towards inclusive access for all.

**CS 3.4.3:** *p46 with additional examples from Thailand.*

- **China** – Establishing a cross-sectoral policy approach centred on pollution reduction and carbon synergy has been key to tackling PM2.5 air pollution and consequences on health.
- **Argentina** – Energy tariffs relying on blanket subsidies continue to promote non-energy-efficient and inequitable consumption patterns from middle- and upper-income segments, which do not contribute to the alignment of mitigation and social equity goals.
- **Thailand** – Social considerations are emerging in climate policies but remain incomplete.

## Annex 2 Cities net-zero strategies analyzed for investment and financing coverage

City	Country	Income group	Document (title, year, URL)	Quantified investment needs	Financing strategy / funding sources	Instruments mentioned
London	UK	High	Net Zero Carbon Pathway for London (2022)	<b>Yes:</b> £75bn to 2030; also frames £6.2bn/yr bill savings	<b>Yes:</b> mobilizing investment; ROI framing	Savings / ROI framing; mobilization of private capital
New York City	USA	High	Pathways to Carbon-Neutral NYC (2021)	<b>Yes:</b> \$1.5–2T (2020–2050)	<b>Yes:</b> “shift investments” / redirected capital framing	Reallocation/ redirected-capital concept
Los Angeles	USA	High	L.A.’s Green New Deal / pLAn (2019)	No numeric total observed	<b>Yes:</b> implementation + funding context (high-level)	Public programmes (non-specific)
San Francisco	USA	High	San Francisco Climate Action Plan (2021)	No numeric total observed	<b>Yes:</b> implementation / funding framing present	Non-specific (implementation tools)
Chicago	USA	High	Chicago 2022 Draft Climate Action Plan (2022)	No numeric total observed	<b>Yes:</b> references to increased funding / investment context	General investment language
Seattle	USA	High	Seattle 2013 Climate Action Plan (2013)	No numeric total observed	<b>Yes:</b> explicitly discusses financing mechanisms	PACE; meter-based financing; loan-type tools
Washington, DC	USA	High	Clean Energy DC Progress Report (2022)	No numeric total observed	<b>Yes:</b> climate finance delivery via city-linked finance entities	DC Green Bank; DC PACE; financing leverage
Toronto	Canada	High	TransformTO Net Zero Strategy (2021)	<b>Yes:</b> \$140–146bn investments vs baseline	<b>Yes:</b> financial analysis of costs / savings relative to baseline	Baseline-relative cost framework; programme investments
Vancouver	Canada	High	Vancouver CEAP council report (2020/updates)	No numeric total observed	<b>Yes:</b> explores fees / charges and measures to drive lowcarbon investment	Fees / charges; incentives
Montréal	Canada	High	Montréal Climate Plan 2020–2030 (2020)	No numeric total observed	<b>Yes:</b> implementation resources referenced	Non-specific

City	Country	Income group	Document (title, year, URL)	Quantified investment needs	Financing strategy / funding sources	Instruments mentioned
Mexico City	Mexico	Upper-middle	Mexico City Climate Action Plan 2014-2020 (2014)	No numeric total observed	<b>Yes:</b> financing via bond issuance described in finance blueprints	Municipal green bonds (2016, 2018)
São Paulo	Brazil	Upper-middle	PlanClima SP Executive Summary (2020/2021)	No numeric total observed	<b>Yes:</b> implementation / partnership framing	Non-specific
Rio de Janeiro	Brazil	Upper-middle	Sustainable Development & Climate Action Plan (Exec Summary) (2021)	No numeric total observed	<b>Yes</b> (high-level)	Non-specific
Buenos Aires	Argentina	Upper-middle	Climate Change Action Plan (English summary) (2010)	No	No finance content observed in summary	—
Paris	France	High	Paris Climate Action Plan 2024–2030 (2025)	No numeric total observed	<b>Yes</b> (high-level implementation)	Non-specific
Berlin	Germany	High	Climate-Neutral Berlin 2050 (2016)	No numeric total observed	<b>Yes</b> (policy + funding programme framing)	Non-specific
Amsterdam	Netherlands	High	Amsterdam Climate Neutral 2050 Roadmap (2019)	No numeric total observed	<b>Yes</b> (investments / implementation framing)	Non-specific
Copenhagen	Denmark	High	CPH 2025 Climate Plan (2012)	No numeric total observed	<b>Yes</b> (municipal investment / partnerships)	Non-specific
Oslo	Norway	High	Oslo Climate Budget (2021, annual)	<b>Yes:</b> quantified annual climate-related allocations	<b>Yes</b> (budget integration)	Climate budget
Stockholm	Sweden	High	Stockholm Climate Action Plan (2024)	No numeric total observed	<b>Yes</b> (investment needs referenced)	Non-specific
Helsinki	Finland	High	Helsinki Emission Reduction Plan 2030 (2024)	No numeric total observed	<b>Yes</b> (implementation)	Non-specific

City	Country	Income group	Document (title, year, URL)	Quantified investment needs	Financing strategy / funding sources	Instruments mentioned
Barcelona	Spain	High	Barcelona climate plan / measures (2024)	No numeric total observed	<b>Yes</b> (investment planning references)	EU-oriented investment framing
Madrid	Spain	High	Madrid Climate Adaptation Action Plan (2024)	No	No investment discussion emphasized in reviewed excerpts	—
Lisbon	Portugal	High	Lisbon Climate City Contract (2024)	No numeric total clearly observed in excerpt	<b>Yes</b> : “investment plan / pipeline” structure	CCC investment plan
Vienna	Austria	High	Vienna Smart Climate City Strategy (2022)	No numeric total observed	<b>Yes</b> (references climate guide / budget approach)	Climate budget referenced
Milan	Italy	High	Milan Air & Climate Plan (2022)	No numeric total observed	<b>Yes</b> (implementation framing)	Non-specific
Rome	Italy	High	Rome Climate City Contract / action plan (2022)	No numeric total clearly observed in excerpt	<b>Yes</b> : CCC investment plan approach	CCC investment pipeline
Warsaw	Poland	High	Warsaw Climate Neutrality Action Plan (2023)	No numeric total clearly observed in excerpt	<b>Yes</b> : CCC investment plan approach	CCC investment pipeline
Dublin	Ireland	High	Dublin City Council Climate Action Plan 2024–2029 (2024)	No numeric total observed on page excerpt	<b>Yes</b> : links CAP with investment plan requirement	Investment plan (EU Mission)
Istanbul	Türkiye	Upper-middle	Istanbul Climate Change Action Plan (2022)	No numeric total observed in excerpt	<b>Yes</b> : references alignment to investment planning	Investment plan alignment (non-specific)
Reykjavík	Iceland	High	Reykjavik Action Plan: Carbon Neutral by 2040 (2016)	No numeric total observed	No finance content observed in excerpt	—
Tokyo	Japan	High	Realization of Zero Emission Tokyo	No numeric total observed	<b>Yes</b> (policy / budget-backed programme framing)	Non-specific
Seoul	South Korea	High	2050 Seoul Climate Action Plan	No	No finance detail observed in excerpt	—
Singapore	Singapore	High	Singapore Green Plan 2030 (2021)	No numeric total observed	<b>Yes</b> (whole-of-nation plan; finance ecosystem framing)	Non-specific

City	Country	Income group	Document (title, year, URL)	Quantified investment needs	Financing strategy / funding sources	Instruments mentioned
Hong Kong	China (HKSAR)	High	Hong Kong Climate Action Plan 2050 leaflet (2021)	No numeric total observed	<b>Yes</b> (green finance pillar explicitly referenced)	Green finance (policy pillar)
Jakarta	Indonesia	Upper-middle	Jakarta Climate Action Plan 2021–2050	No	No finance detail observed in excerpt reviewed	—
Bangkok	Thailand	Upper-middle	Bangkok City Climate Investment Opportunities Diagnostic (2024)	<b>Yes</b> (investment opportunities diagnostic: quantified pipeline/costing focus)	<b>Yes</b>	Investment opportunities diagnostic
Kuala Lumpur	Malaysia	Upper-middle	Kuala Lumpur Climate Action Plan 2050 (2024)	No numeric total observed	<b>Yes</b> (finance facility / plan development context)	C40 finance facility support context
Mumbai	India	Lower-middle	BMC Climate Budget Report FY 2024–25 (2024)	<b>Yes</b> : ₹10,224.24 crore climate-relevant capex (32.18% of capex)	<b>Yes</b> (budget tagging / mainstreaming)	Climate budget
Cape Town	South Africa	Upper-middle	City of Cape Town Climate Change Action Plan (year not stated in snippet)	No numeric total observed	<b>Yes</b> (explicitly references financial mechanisms, tariffs, investment / divestment)	Tariffs; financial mechanisms
Johannesburg	South Africa	Upper-middle	City of Johannesburg Climate Action Plan (year not stated in snippet)	<b>Yes</b> : CAPEX need cited (R1.3bn for prioritized adaptation actions)	<b>Yes</b>	Funding / investment framing
Lagos	Nigeria	Lower-middle	Lagos Climate Action Plan (2020–2025)	No numeric total observed	<b>Yes</b> (finance / implementation framing)	Partnerships; enabling measures
Accra	Ghana	Lower-middle	Accra Climate Action Plan 2020–2025	No	No finance detail observed in excerpt	—
Sydney	Australia	High	City of Sydney Environmental Strategy 2025–2030 (2025)	No	No finance detail observed in excerpt	—
Melbourne	Australia	High	Melbourne Climate Change Mitigation Strategy to 2050 (2018)	No	No finance detail observed in excerpt	—

City	Country	Income group	Document (title, year, URL)	Quantified investment needs	Financing strategy / funding sources	Instruments mentioned
Auckland	New Zealand	High	Te Tāruke-ā-Tāwhiri: Auckland's Climate Plan (overview, 2020)	No	No finance detail observed in excerpt	—
Wellington	New Zealand	High	Te Atakura – First to Zero Update (2021)	No	No finance detail observed in excerpt	—
Bologna	Italy	High	Bologna Climate City Contract (2023)	No numeric total observed in excerpt	<b>Yes</b> (investment plan / portfolio structure)	CCC investment plan
Porto	Portugal	High	Porto Climate Neutrality Action Plan (CCC) (2024)	No numeric total observed in excerpt	<b>Yes</b> (investment plan / portfolio structure)	CCC investment plan
Thessaloniki	Greece	High	Thessaloniki Climate Neutrality Action Plan (CCC) (2023)	No numeric total observed in excerpt	<b>Yes</b> (investment plan / portfolio structure)	CCC investment plan

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## Chapter 2

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