Centre for Climate and Energy Policy

Long-term greenhouse gas emissions strategies: a synthesis of best practice

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Abstract

Long-term strategies (LTS) to cut greenhouse gas emissions are important tools for understanding possible pathways towards long-term emissions goals and their implications. High-quality LTS can guide decision-making in policy, investment and society, and provide a comprehensive foundation of evidence for broader public debate. Some countries have submitted or are preparing official LTS to the Paris Agreement process, others have strategies to underpin long-term emissions goals, prepared either by governments or other bodies. They take a range of forms, include a variety of elements, and use different processes. This paper provides a conceptual synthesis and empirical analysis of LTS, and identifies elements of best practice in *process, design* and *implementation*. It illustrates these best-practice elements by drawing on examples of LTS and LTS-type studies and processes. Taken together, the best-practice elements can be considered a benchmark for national or sub-national LTS frameworks.

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Contents

Summary of findings

Long-term emissions strategies (LTS) are an important decision support tool for understanding possible pathways towards long-term emissions goals. In principle, LTS should set out possible enablers and obstacles, risks and opportunities within a consistent framework. The aim of high-quality LTS is to be a guide to decision-making in policy, investment and society, and to provide a comprehensive foundation of evidence for broader public debate.

The Paris Agreement asks that all Parties should strive to formulate and communicate LTS that are 'mindful' of the agreement's Article 2 to the United Nations Framework Convention on Climate Change (UNFCCC). Some countries have submitted LTS under the Paris Agreement process, others are preparing LTS, and many jurisdictions have processes or documents that contain elements of LTS.

This paper provides a conceptual synthesis and empirical analysis of development of LTS, and identifies elements of best practice in *process, design* and *implementation*. The paper does not assume a particular emissions reduction target – instead, it lays out how a best-practice LTS enables consideration of the full range of options, trajectories, costs and benefits associated with any specified target, and how these might change under different scenarios.

- Elements of best-practice *process* include:
    - to build on existing related strategies and to align with institutional, legislative, or governance frameworks;
    - to employ 'whole of government' approaches to planning and designing LTS;
    - for independent institutions to have a prominent advisory role in the process;
    - to facilitate cooperation beyond government agencies in creating an LTS; and
    - to make broad-based stakeholder consultation an integral part of the process.
- Elements of best practice *design* include:
    - a long-term vision and target, including how trajectories align with development outcomes, Paris Agreement commitments and other emissions goals;
    - roadmaps for integration of LTS with broader economic and societal objectives, especially with regard to potential economic opportunities at a national and sub-national level, economic transition and sustainable development;
    - analysis of a comprehensive range of climate change mitigation options, taking into account costs and benefits including externalities and avoided costs;
    - modelling and scenario development that combines quantitative and qualitative elements, multiple models sets of assumptions, explores the often large uncertainties in future technological and economic parameters, identifies 'critical path' decisions and considers decision-making under deep uncertainty;

- o climate change adaptation planning based on broad-based sectoral vulnerability assessments
- o recognition of potential transformational change trajectories, including in specific technologies as well as system-wide interactions.
- Elements of best practice *implementation* include:
  - o the identification of feasible implementation pathways, including in governance and policy and in sectoral and sub-national dimensions;
  - o a robust implementation governance framework, including strong institutions, clarity about respective roles, a flexible policy framework, extensive and sustained stakeholder engagement;
  - o mobilisation of finance and technology development;
  - o clear, consistent and extensive public communication, and
  - o well-defined plans for monitoring, evaluation and review, including the capacity to refine implementation plans on the basis of experience and new evidence.

The paper illustrates these best-practice elements through drawing on examples of current practice in a wide range of comparative national and sub-national LTS and LTS-type studies and processes. The analysis is extensive yet lays no claim to comprehensiveness, and specific examples are chosen for their salience rather than as representative.

Taken together, the best-practice elements can be considered to be a benchmark for national or sub-national LTS frameworks. Of course, elements would be expected to be tailored according to specific context and objectives. In addition, there is considerable complexity to be worked through in many technical aspects of the elements, such as identification and quantification of costs and benefits, technology path modelling, and implications of deep uncertainty. Further work is to be done as analytic approaches evolve and LTS frameworks continue to be refined.

1 Introduction

Long-term emissions goals have seen increasing interest and emphasis in international and national climate change policy. The Paris Agreement enshrined a global commitment to limit temperature rise to well below 2 degrees Celsius above pre-industrial levels and pursues limiting temperature increase to 1.5 Celsius (UNFCCC, 2015). Net zero emissions targets or goals are increasingly considered and have been officially adopted by some countries as well as by sub-national governments.

But for a long-term target to be meaningful as a guide to policy and investment, it needs to be translated into a strategy – a plan of action toward achieving a defined goal, supporting decision-making under unavoidable uncertainty, identifying possible enablers and obstacles, risks and opportunities.

Long-term emissions strategies

The Paris Agreement's Article 4.19 states that all Parties should strive to formulate and communicate their 'long-term low-emissions development strategies' (LT-LEDS, or LTS for short) that are 'mindful' of the agreement's Article 2 to the United Nations Framework Convention on Climate Change (UNFCCC, 2015).

The nature of the transformational change required for decarbonisation has also renewed the focus on long-term strategies. The Paris Agreement's long-term goal requires rapid, deep and wide-ranging transitions across energy, transport, forestry, industry, infrastructure, buildings, and agricultural and land-use systems (Gillard *et al.*, 2016; Geels *et al.*, 2017a; DDPLAC Consortium, 2020). The scale of systemic change, low-carbon investment, technological innovation, sustainability transitions and societal transformations necessary for decarbonising economies, makes it a complex process. In this context, a long-term strategy can potentially allow for radical restructuring through the process of 'deliberation, probing and learning' (Voß, Smith and Grin, 2009).

Strategy development can help identify low-emissions pathways, in a context of uncertainty, cognizant of national realities and socio-economic objectives (Sartor *et al.*, 2017; Falduto and Rocha, 2020). By weaving a long-term horizon into policymaking, long-term strategies can help anticipate and address structural and transformational change, including broader economic changes, regional impacts and social effects.

As of 22 February 2021, 28 countries and the European Union have formally submitted their long-term strategy to the UNFCCC.[1] For many of these, the strategies are in the context of net-zero emissions commitments. Several European countries (Sweden, UK, France, Hungary and Denmark) and New Zealand have committed to legally-binding carbon neutrality targets by mid-century. Several East Asian countries, such as China, Japan and South Korea, have pledged net-zero emissions goals by mid-century or soon after. Several European countries have submitted long-term strategies in response to the European Parliament's Regulation 2018/1999 (European

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[1] https://unfccc.int/process/the-paris-agreement/long-term-strategies

Commission, 2018), which requires member states to prepare long-term low greenhouse gas emission development strategies every ten years with a perspective of at least 30 years.

Long-term strategy goals, processes and elements

In practice, the aim of such a strategy is integrating considerations of sustainability, climate change adaptation and socio-economic development with long-term emission reduction goals (World Resources Institute, 2018; Rocha and Falduto, 2019). In doing so, countries are encouraged to develop a long-term vision, given country-specific circumstances, that guides short-term policymaking.

Long-term strategies aim at developing an adaptive policy framework that guides long-term planning and investment. LTS development processes aim to build on political coordination, public discussion, and stakeholder engagement to identify potential challenges and promote public acceptance and successful implementation (Sachs, Schmidt-Traub and Williams, 2016; Hans *et al.*, 2020).

However, approaches to LTS development differ substantially. The Paris Agreement prescribes neither elements nor process of LTS. The process and content of a national long-term emission reduction strategy is highly context-specific.

Nevertheless, it is possible to identify best-practice processes and elements that to some extent can be generalised. An examination of the various approaches, adopted in diverse jurisdictions, for long-term policy design can collect best-practice experience by drawing on technical details of the strategy development process, institutional and governance frameworks and stakeholder consultation. Lessons from other jurisdictions' experience can form an additional source for evidence-based policymaking (Head, 2016).

Analysis in this report

Here, we first develop a framework for identifying best-practice elements of a long-term emissions reduction strategy. We then survey the content of the long term strategies and illustrate best-practice examples from LTSs submitted to UNFCCC, as well as net-zero and long-term decarbonisation strategies by national governments and independent bodies that have produced national long-term emission reduction strategies.

We restrict this analysis to selected countries, based on the size of the economy, design elements of LTS and innovative elements in strategy design.

We present these examples as potential lessons for national and also sub-national governments in developing LTS.

2 Analytical framework: LTS process, design elements and implementation elements

Our analytical framework separately considers two characteristics of designing best-practice long-term decarbonisation strategies. First is the process of how strategies are developed; second are its design elements, that is what is covered in the strategies; third are implementation elements.

LTS development process

The long-term strategy design process should begin with an assessment of the current emissions and development trends, national priorities, and vulnerability assessment of economic sectors and communities (Rocha and Falduto, 2019). Towards this, building upon existing long-term strategies produced under national or international obligations, such as for climate change mitigation, adaptation or development planning, could inform long-term strategy design (Rocha and Falduto, 2019). Collected data and model-based analyses from existing long-term climate strategies, can inform the policy design process. Similarly, building upon or aligning with institutional, legislative, or governance frameworks, created for existing long-term strategies, could increase efficiency (Institute, 2020).

For managing the design process, nominating a central institution, close to the highest level of government can induce political stability for the process (Levin *et al.*, 2020). Investing in robust institutional frameworks with strong technical, managerial, and financial capacity helps develop and implement planned policies (Recalde, 2016). Such a lead institution could seek a whole of government approach by assembling and coordinating resources from across government agencies.

Broad-based stakeholder engagement

For developing a robust long-term strategy, it is crucial to design processes for effective stakeholder engagement that cut across national and sub-national governments, institutions, academia, industry and civil society (Levin *et al.*, 2018, 2020). In the context of socio-economic transformations resulting from decarbonisation, engaging with potentially negatively impacted industries, businesses and communities can inform the policy process on a fair and just transition (Rocha and Falduto, 2019).

The UNFCCC at its 16th Conference of Parties (COP16) (Decision 1/CP.16, 8) also recognised that a broad-based stakeholder engagement at the global, regional, national and local level is vital for effective action on climate change (UNFCCC, 2011). Effective stakeholder consultation can engage critical parties, such as governments, businesses, civil societies and the scientific community in contributing knowledge and expertise towards assessment and review of envisaged long-term strategy (Sachs, Schmidt-Traub and Williams, 2016).

Broad-based engagement also allows for strengthening ownership, support and consensus amongst stakeholders for the designed policy (Sartor *et al.*, 2017; IDB and DDPLAC, 2019). Consensus building through iterative rounds of engagement with evidence-based dialogue

addressing affected stakeholders can also potentially instil political stability and make it harder for successive governments to repeal strategy implementation measures (Sartor *et al.*, 2017).

Additionally, countries could establish independent institutions tasked with supervising and coordinating the process across different agents, such as government institutions, civil society, industry and governance at the national/regional/local level (Rocha and Falduto, 2019). Establishment of such supervisory, independent institutions can also strengthen the political credibility of the process.

Table 1: LTS Development Process – framework and literature

Element	Aspect	References
LTS development process	Build upon existing long-term strategies produced under national or international obligations, such as for climate change mitigation, adaptation or development planning. Building upon or aligning with institutional, legislative, or governance frameworks	(Levin *et al.*, 2018; Rocha and Falduto, 2019; Institute, 2020)
	A whole of government approach for planning and designing LTS Independent lead institutions for supervising/managing/coordinating the design process	(Levin *et al.*, 2018; Rocha and Falduto, 2019)
	Cooperation and broad-based stakeholder consultation	(UNFCCC, 2011; Sartor *et al.*, 2017; De Pinto *et al.*, 2018; Levin *et al.*, 2018; IDB and DDPLAC, 2019; Coalition of Finance Ministers for Climate Action, 2020; Hans *et al.*, 2020)

LTS design elements

Given systemic socio-economic transformations required for achieving the Paris Agreement's goals, a comprehensive long-term strategy would aim to address all aspects of design, implementation, governance, and the associated socio-economic impacts of the envisaged decarbonisation strategy (Ribera and Sachs, 2015; Bataille *et al.*, 2016; Waisman *et al.*, 2019). Such a strategy could potentially include a long-term decarbonisation vision with a mid-century time-frame, development considerations, climate change mitigation and adaptation elements, model-based scenario analyses with sectoral pathways and strategies, implementation, governance, monitoring and revision frameworks, resource and capacity assessment and a long-term financial and investment vision (Levin *et al.*, 2018; World Resources Institute, 2018; Rocha and Falduto, 2019; Waisman *et al.*, 2019; Hans *et al.*, 2020; Institute, 2020).

However, the Paris commitment itself does not dictate the scope and elements of long-term strategies. Article 4 of the Paris Agreement recognises countries' "common but different responsibilities and respective capabilities, in the light of different national circumstances" (UNFCCC, 2015). Therefore, depending on country-specific circumstances, national priorities,

financial and technological resources and capability and capacity constraints, countries can choose a differentiated level of detail and depth at which an LTS addresses each aspect.

Long-term vision and target and mitigation elements

Any such strategy's fundamental element will be a long-term vision for a climate-resilient and low-emissions development with an associated mitigation target.

COP 21 decided that the time frame for such strategies are to be mid-century and invited parties to communicate long-term strategies consistent with the temperature goal of limiting the increase in global average temperature to well below 2 degrees Celsius (UNFCCC, 2016, para. 35). The 2050 time-frame is in line with the IPCC's findings on the impacts of global warming of 1.5 degrees Celsius (IPCC, 2018) and allows for planning long-term infrastructure changes required to achieve mitigation goals (Rocha and Falduto, 2019). Also, Article 4 of the Paris Agreement aims to reach global peaking of greenhouse gas emissions as soon as possible (UNFCCC, 2015).

Therefore, country LTSs consistent with Paris Agreement commitments and COP decisions would aim for a mid-century time-frame with comprehensive coverage of greenhouse gases across all sectors of the economy. Such LTSs would also include a quantifiable trajectory of economy-wide emissions reduction with visibility when national emissions peak. Additionally, such strategies could also include an outlook of when countries will achieve carbon dioxide (CO_2) neutrality and net-zero greenhouse gas emissions. This could inform if envisaged emissions trajectory is consistent with the IPCC's benchmark of net-zero CO_2 by the year 2050 and net-zero GHG emissions by the year 2070 (IPCC, 2018).

Projections for global emissions levels for 2030 as per countries' national pledges (the Nationally Determined Contributions or NDCs under the Paris Agreement) and existing policies in aggregate are inconsistent with the Paris Agreement commitment of limiting temperature rise to less than 2 degrees (IPCC, 2018; Schaeffer *et al.*, 2019; Falduto and Rocha, 2020). In this context, setting short-term emission reduction targets by reverse-forecasting (backcasting) a long-term emissions reductions trajectory can reconcile short-term goals with long-term objectives (Waisman *et al.*, 2019). Modelling using integrated assessment models also suggest the importance of aligning the quantity of short-term emissions reduction with long-term emission reduction targets as economies have limited ability to undergo a rapid transition to a low-carbon pathway (Vogt-Schilb and Hallegatte, 2017). Additionally, modest short-term emissions targets will result in a higher mitigation cost in later years with limited policy options (Riahi *et al.*, 2015).

Simultaneously, long-term strategies should recognise the need for flexible policy frameworks given inherent uncertainties surrounding technological change and socio-economic transformation. These uncertainties influence optimal policy pathways and have associated costs of adjustment (Markandya and Pemberton, 2010; Zeng *et al.*, 2011; Mathy *et al.*, 2016). The optimal policy mix for a country may also vary over time, depending on the political climate and stakeholder acceptance (Rogge and Reichardt, 2016; Geels *et al.*, 2017b). In this context, dynamic policy pathways (Haasnoot *et al.*, 2012; Mathy *et al.*, 2016) allow for divergence or adjustment of policy, as per a defined policy action sequence in case of policy failure (Mathy *et al.*, 2016; Bataille, 2020). For this, countries will need to carry out periodic policy assessment to monitor specific performance indicators. Countries could integrate periodic monitoring, assessment and review of

adopted policy frameworks against a pre-set benchmark and change course depending on the chosen policies' success.

Modelling and scenario development

Climate policymaking occurs in the backdrop of uncertainties around climate sensitivities, temperature rise associated with socio-economic impacts, economic growth projections, political instability, unplanned future policy responses to unanticipated shocks and unpredictable policy impacts (Termeer, Biesbroek and Van den Brink, 2012; Rosenbloom, Meadowcroft and Cashore, 2019). Countries design climate policy frameworks and policies with uncertainties surrounding their impact, effectiveness, and feasibility in this context.

Therefore, in a comprehensive long-term strategy, a robust analytical framework should underpin the planning for the long-term mitigation target.

As a first step, countries can build upon current assessments and trends of economy-wide and sector-wise greenhouse gas emissions with a national, regional and local perspective. This assessment can indicate sectoral pathways and a long-term outlook for greenhouse gas emissions based on the current policy framework.

Following this, a combination of quantitative and qualitative analyses with robust stakeholder engagement can help develop policy pathways (World Resources Institute, 2018; Rocha and Falduto, 2019; Sato and Altamirano, 2019). Development of different potential decarbonisation pathways for a range of uncertainties also enables the design of robust strategies (Waisman *et al.*, 2019).

For robust analysis, countries can develop policy pathways with different mitigation targets as well as identify potential pathways and trajectories for a mitigation target (Sartor *et al.*, 2017; Rocha and Falduto, 2019; World Resources Institute, 2019)

Computer modelling tools, such as sectoral, integrated assessment or energy-system models for developing long-term scenarios or policy pathways, can assist with quantifying potential interactions with climate change policy. For example, Integrated Assessment Models that couple energy-system, economic and climate science models find application for assessing the technological and economic feasibility of envisaged long-term policy pathway.

Modelling tools can help develop multiple scenarios with different assumptions about technological development, economic development, climate impacts, negative emissions, population growth and other socio-economic variables. A sensitivity analysis can then reveal the extent to which these assumptions affect outputs such as GDP and emissions. Transparent communication of quantitative model results can also help develop a better understanding amongst stakeholders (Weitzel *et al.*, 2019).

Based on capability and capacity constraints, countries can adopt their model of choice. These model choices could be jurisdiction-specific or global models that can be customised. Alternatively, countries can choose top-down, bottom-up or hybrid models.

Models, however, are simplified with assumptions based on imperfect knowledge. Additionally, underlying data and assumptions can change over time. For developing a good understanding

among stakeholders, long-term strategies should transparently communicate details on the underlying methodology for scenario development, the type and name of the model used as well as underlying assumptions regarding negative emissions, technological innovation and planned deployment across sectors, climate impacts and reliability of current GHG emission data (Rocha and Falduto, 2019; Sato and Altamirano, 2019; Institute, 2020).

Transformative change

Economy-wide decarbonisation in some instances requires fundamentally different technologies and approaches. To the extent that LTS aim for very deep emissions reductions and/or net zero emissions, strategies need to include analysis of transformative aspects. This includes both an awareness of possible, likely or necessary fundamental changes within individual sectors, and of system-wide reconfigurations.

Long-term strategies for full decarbonisation will usually require sector- or technology-specific plans and instruments (Sandén and Azar, 2005). Further, the extent and wide-spread nature of the required decarbonisation will require cross-sectoral coordination. Examples include the integration of domestic PV installations and electric vehicles in power grids, the expected future role of large scale industrial energy users acting as virtual batteries through flexible demand management, the systems for both production and transport of hydrogen as well as the adaptation of industrial processes to their consumption, and new information technology solutions to manage these new systems. This interconnectedness calls for 'whole systems reconfiguration', and call for policy approaches that ensure that optimal solutions for a single technological need, do not lock out or hinder transitions in related technological fields (Geels, 2018; McMeekin, Geels and Hodson, 2019).

Long-term strategies should further consider the timing of actions including policy interventions in different sectors, and recognize that the development of technologies, from academic idea to prototyping to commercially competitive solution, are multi-decadal processes. Wind and solar power have become commercially competitive solutions in many places and applications over the last few years, but have spent as much as five decades in R&D, demonstration and subsidized deployment phases (Bergek *et al.*, 2008; Bento and Wilson, 2016; Markard, 2018). Other technologies for hard-to-abate sectors , currently remain in early stage development, such as in long-distance, heavy-duty transport as well as in aviation and maritime shipping, industrial heat and power, and in industrial processes such as the production of ammonia, steel and cement. Long-term policy strategies can assess whether technological development and support measures through 2030 are on track to allow full decarbonisation of these sectors by 2050.

Lastly, despite the rapid growth of wind and PV, and electric vehicles in a small number some markets worldwide, these have still captured small market shares that are yet to seriously challenge conventional technologies in most markets. As they scale up they increasingly provide potential for large scale economic benefits arising from investment and job creation in new growth sectors (Jotzo, Longden and Anjum, 2020; WWF and E&Y, 2020).

However the required transformation to net-zero emissions will necessarily also require a structural shift away from the fossil fuel and other conventional technology sectors. Managing this adjustment will include retraining of workforces and possible compensation for lost income,

possible compensation for stranded assets, and economic restructuring plans for regions that are particularly dependent on currently incumbent (fossil fuel) industries (Abraham, 2017; Smith, 2017; Coenen, Campbell and Wiseman, 2018). Long-term strategies can look ahead to likely structural transformations, across sectors and communities that could potentially arise from a transition to a low-emissions pathway. An LTS can identify sectors, affected workers and vulnerable communities and plan policy pathways addressing regressive impacts of the shift to a low-carbon economy. Such policy pathways, aiming at a just and equitable transition, can increase sustained support for countries' long-term decarbonisation objectives (World Resources Institute, 2018).

Adaptation planning

The Paris Agreement encourages long-term strategy design to be 'mindful' of its Article 2, which urges countries to increase their ability to adapt to adverse impacts of climate change and increase climate resilience (UNFCCC, 2015). In this context, including adaptation goals as an element in the long-term strategy presents opportunities for alignment of adaptation and resiliency planning with mitigation and development priorities (Levin *et al.*, 2018). It can also help understand the trade-offs between policy pathways and their interaction with adaptation planning and climate mitigation goals (World Resources Institute, 2018).

Resilience and adaptation planning is particularly crucial for less-developed countries vulnerable to climate change (Coalition of Finance Ministers for Climate Action, 2020). For some other countries, climate change adaptation directly links to development objectives due to current intensifying impacts of climate change, such as a sea-level rise or extreme climate events.

Inclusion of adaptation goals in long-term strategies can identify linkages and synergies between mitigation and adaptation actions (Rocha and Falduto, 2019). Towards this, a vulnerability assessment of the impacts on infrastructure, biodiversity, land-use and ecosystem services can identify vulnerable sectors and communities and inform long-term policy design (Institute, 2020). Country LTSs could identify goals for increasing the adaptive capacity and resilience of identified sectors and communities. Countries may also choose to link existing national adaptation plans developed in response to other international obligations (Levin *et al.*, 2018).

Development objectives – SDGs and Just Transition

The Paris Agreement's Article 2 (UNFCCC, 2015) also aims to align national development objectives and equity concerns from decarbonisation to mitigation and adaptation goals. Integration of development objectives into long-term decarbonisation strategies allows for identifying synergies and trade-offs between mitigation, adaptation and developmental policy planning (Rocha and Falduto, 2019). In particular, for adaptation and mitigation policy, a long-term vision can help identify and manage negative linkages and trade-offs, which get overlooked in stand-alone plans (Hallegatte, 2009; Watkiss and Klein, 2019).

In this context, an LTS could quantify and reflect on how planned sectoral pathways achieve climate and non-climate goals (DDPLAC Consortium, 2020). A quantified estimate of potential synergies, trade-offs and associated development impacts in terms of projected economic growth, health outcomes, job creation and poverty reduction, can assist with rallying political support for

policy implementation (Levin *et al.*, 2018). Also, the alignment of other objectives with climate mitigation goals helps build stakeholder support as long-term benefits of climate mitigation aren't always easy to characterise and quantify (Geels *et al.*, 2017b).

Table 2: LTS Design Elements – framework and literature

Element	Aspect	References
Long-term vision and target	Time-frame for strategy/consistency with the Paris agreement	(UNFCCC, 2016; Levin *et al.*, 2018; World Resources Institute, 2018; Investor Group on Climate Change, 2019; Rocha and Falduto, 2019)
	Long term quantified outcome with coverage of gases and clear trajectory of emissions reduction with visibility of when emissions are expected to peak	(Levin *et al.*, 2018; World Resources Institute, 2018; Rocha and Falduto, 2019; Hans *et al.*, 2020; Institute, 2020)
	Established link/synergy between mitigation and adaptation plan and development outcomes	(Levin *et al.*, 2018; Watkiss and Klein, 2019; Hans *et al.*, 2020; Institute, 2020)
	Clear description of how long term strategy aligns with Paris Agreement commitments and targets including when CO2 neutrality and net-GHG neutrality will be achieved.	(World Resources Institute, 2018; Investor Group on Climate Change, 2019; Schaeffer *et al.*, 2019)
Mitigation elements	Alignment of NDCs with LTS, backcasting for interim targets using long-term benchmarks	(IDB and DDPLAC, 2019; Waisman *et al.*, 2019)
	Clear communication of methodology used for projecting scenarios with information on the type and name of the model. Clear identification and communication of assumptions made re: negative emissions, technological innovation and deployment across sectors, climate impacts and reliability of current GHG emission data.	(World Resources Institute, 2018; Sato and Altamirano, 2019; Institute, 2020)
Modelling and scenario development	Use of national modelling with quantified scenarios and indicators, use of global models with local detail considering multi-dimensional uncertainties, including a description of qualitative analysis undertaken for mitigation target.	(Trutnevyte *et al.*, 2016; Sartor *et al.*, 2017; Van Soest *et al.*, 2017; Investor Group on Climate Change, 2019; Rocha and Falduto, 2019; Sato and Altamirano, 2019; Waisman *et al.*, 2019; Weitzel *et al.*, 2019; Institute, 2020)
	Use of a combination of qualitative and quantitative approaches, including different types of quantitative modelling eg top-down and bottom-up models	(World Resources Institute, 2018; Rocha and Falduto, 2019; Sato and Altamirano, 2019)
	Consideration of policy pathways under multiple alternative futures, explicitly exploring assumptions that may seem unlikely. Such pathways can be associated with different emission reduction goals or different scenarios that lead to the same target.	(Sartor *et al.*, 2017; Rocha and Falduto, 2019; World Resources Institute, 2019)

	Integration/synergy of national adaptation plans to long-term strategy.	(Levin *et al.*, 2018; World Resources Institute, 2018; Rocha and Falduto, 2019; Coalition of Finance Ministers for Climate Action, 2020)
Transformative change	Whole systems reconfiguration incl. plans for each technology or sector	(Geels, 2018; Levin *et al.*, 2018; McMeekin, Geels and Hodson, 2019)
	Recognition of the need for early action to meet long-term targets	(Sandén and Azar, 2005; Markard, 2018)
	Managed phase-out fossil fuel sectors and planning for just transition in sectors that experience decline	(Abraham, 2017; Smith, 2017; Coenen, Campbell and Wiseman, 2018; IDB and DDPLAC, 2019; Rocha and Falduto, 2019; Coalition of Finance Ministers for Climate Action, 2020; Hans *et al.*, 2020; WWF and E&Y, 2020)
Adaptation planning	Goals for enhancing adaptive capacity, increase resilience and reduce vulnerability across sectors, vulnerability assessment of sectors of the economy	(Levin *et al.*, 2018; World Resources Institute, 2018; Institute, 2020)
	Integration of LTS with sustainable development objectives	(Levin *et al.*, 2018; World Resources Institute, 2018; IDB and DDPLAC, 2019; Rocha and Falduto, 2019; Coalition of Finance Ministers for Climate Action, 2020; Hans *et al.*, 2020)
Development objectives – Sustainable Development Goals (SDGs), 'just transition' objectives	Clearly quantified assessment of gains in terms of economic growth employment etc.	(Levin *et al.*, 2018)
	Harmonisation between NDCs and long-term target/Milestone targets	(Levin *et al.*, 2018; World Resources Institute, 2018; Rocha and Falduto, 2019; Vener *et al.*, 2019; Falduto and Rocha, 2020)

LTS implementation elements

Long-term emissions strategy development processes and documents can also include frameworks or plans for implementation of the strategies. Several types of implementation elements are identified.

Implementation pathway

Provisions in the Paris Agreement create the need to align short-term and long-term climate goals by inviting parties to communicate NDCs and LTSs by 2020 and mandating a five-year review cycle for NDCs. This is important to avoid inconsistencies between short-term targets defined by NDCs and long-term targets defined by LTSs (Schaeffer *et al.*, 2019). Also, keeping sight of long-term mitigation goals while designing policies and strategies for the short/mid-term, can avoid implementing policy packages that are adequate for achieving short-term targets but fall short for achieving long-term goals (DDPLAC Consortium, 2020; Falduto and Rocha, 2020).

Based on defined long-term mitigation target and interim milestones, long-term emission reduction strategies can inform sectoral pathways needed for achieving the national ambition of climate mitigation efforts and its implications. These strategies can help identify risks and opportunities at the sector-level, cross-sectoral dependencies and associated infrastructure requirements (Investor Group on Climate Change, 2019). Countries can then identify critical sectors and associated action items for increasing sectoral capacity for decarbonisation. Alternatively, given capacity constraints, countries might choose to focus on specific sectors based on their current or projected emissions intensiveness or relevance to their economy.

A good sectoral strategy development, within the context of LTS design, could include sectoral emissions reduction targets, identification of associated sectoral policies, the establishment of short and long-term targets, consideration of cross-sectoral linkages and development of sectoral socio-economic transition plan (Levin *et al.,* 2018)

Sectoral strategies are also vital as sectoral policies guide investments by the public and private institutions. For example, the Investor Group on Climate Change (2019) in Australia highlighted the need for economy-wide assessment of Australia's investment needs for meeting Paris Agreement obligations. They reasoned that such an assessment carried out as part of long-term strategy development can unlock capital from institutional investors.

For designing coherent and efficient sectoral strategies, countries can build upon existing national/regional/sub-national/sectoral strategies, and policies (Levin *et al.*, 2018). LTSs also provide opportunities for integration of national climate and/or energy policy framework. For example, the European Commission requires member states' national long-term strategy, submitted under EU regulation (EU/2018/1999), to be consistent with their upcoming integrated national energy and climate plan for 2021-2030 (European Commission, 2018).

Additionally, development of sub-national or regional implementation plans can accommodate differing climate mitigation requirements across jurisdictions or regions while also making the objectives more relatable to local stakeholders and governing institutions (Seneviratne *et al.*, 2016; Samadi *et al.*, 2018). Engagement of governmental and non-governmental actors can also support a more comprehensive and ambitious climate policy (Hultman *et al.*, 2020). Countries could also aim to mainstream successful innovative practices by organising connections between national, regional and local domains (Termeer, Dewulf and Biesbroek, 2017).

Implementation framework

Long-term strategies should include details on the envisaged institutional framework for governance. The stringency of the governance framework, especially the extent to which actions are binding, can affect actual delivery during the implementation phase (Oberthür, 2019). A good strategy would reflect on the role and responsibilities of national/regional/sub-national governmental and non-governmental institutions in operationalising the strategy (World Resources Institute, 2018). Countries can also choose to carry-over institutional set-ups established during the design phase for the implementation stage. Similarly, independent institutions established during the design phase can act as supervisory bodies responsible for coordinating and implementing the strategy. Engagement of independent experts during the implementation may also increase stakeholder consensus while lending political credibility to the process (Sartor *et al.*, 2017).

While long-term strategies are voluntary, adopting framework legislation to guide their development can ensure adequate implementation by establishing political and legal accountability mechanisms (Bennett, 2018). Globally, climate change laws have increased by a factor of 20 between 1997 and 2017 through legislative acts of parliament or executive policies as legislative instruments (Nachmany *et al.*, 2017). Enactment of climate laws has helped to support decreasing emissions intensity with legislative acts being more effective than executive orders (Eskander and Fankhauser, 2020). Therefore, several countries have enacted legislation to enforce provisions on emissions reduction in NDC, LTS and net-zero strategies.

Stakeholder consultation processes established during the LTS design phase should be utilised iteratively during the implementation process to ensure participation and buy-in from all relevant parties.

Monitoring, evaluation and review

To ensure accountability and effective implementation of long-term strategies, monitoring, reporting and review mechanisms are required (Oberthür, 2019). Given the uncertainty related to long-term planning and the pace of technological innovation, it is vital to include monitoring and adjustment provisions in long-term strategy design. The monitoring plan should identify institutions tasked with the role and assign their responsibilities. The monitoring plan should also include details on the review's scope, planned frequency, associated metrics and tools and processes required for conducting an assessment. (Rocha and Falduto, 2019; Institute, 2020).

While the Paris Agreement's provisions do not specify a periodic or harmonised (with NDC) revision of the LTS, underlying uncertainties around climate change impacts, technological innovation and policy pathways make it crucial. Periodic revision of LTSs with NDCs will allow an informed understanding of underlying uncertainties and potential realignment of policy pathways along with the latest scientific insight and technological innovation (DDPLAC Consortium, 2020; Hans *et al.*, 2020).

Mobilisation of finance and technology development

A long-term strategy can also identify funding and financing mechanisms for required investments in institutions, infrastructure and technological innovation in the long and short term. Towards this, countries can estimate investment and finance needs by translating sectoral finance requirements (IDB and DDPLAC, 2019) and identify critical areas or sectors for investment by mapping against available domestic resources (Hans *et al.*, 2020). By identifying resource requirements for critical areas at the outset, countries may also potentially leverage international finance options. Additionally, clear communication of planned public investments and required private investment can encourage private investments by providing policy and regulatory certainty (Rocha and Falduto, 2019).

The Paris Agreement recognises the importance of aligning investment decisions with low-emissions pathways that aim at sustainable development (UNFCCC, 2015). In this context, long-term strategies can guide financial and investment vision and reduce stranded assets risk (Rocha and Falduto, 2019).

In the Australian context, for developing a long-term strategy, the Investor Group on Climate Change recommended alignment of long-term strategy with the Paris Agreement commitments using a scenario-based analysis and extensive stakeholder consultation. They also recommended synergy between climate mitigation and adaptation strategies and building upon existing public and private sector processes to develop an investable long-term strategy (Investor Group on Climate Change, 2019).

Transparent communication

Finally, country LTSs should capture the entire development process and planned implementation transparently and unambiguously with clearly defined scope and targets. Transparency in communication can promote an informed understanding and support amongst stakeholders, guide domestic policy development and enable a global analysis of emissions projections (Levin *et al.*, 2018; Institute, 2020).

Countries LTSs could also be transparent in communicating the LTS design process's existing limitations due to limited capacity or constrained technical and financial resources. This could enable international support in capacity building in constrained areas (Hans *et al.*, 2020).

Documents related to or underpinning many LTS are available publicly, eg from the UNFCCC website, from websites of government ministries/departments or agencies, independent commissions and other organisations.

Table 3: LTS Implementation Elements – framework and literature

Element	Aspect	References
Implementation pathway	Linkages with existing policies and regulation	(Recalde, 2016; Levin *et al.*, 2018; Rocha and Falduto, 2019; Institute, 2020)
	Integration of national energy/climate plan	(Institute, 2020)
	Synergies with sub-national plans	(Samadi *et al.*, 2018; Hultman *et al.*, 2020)
	Sectoral pathways covering opportunities and synergies across sectors. Identification of key sectors that drive emissions	(Recalde, 2016; World Resources Institute, 2018; Investor Group on Climate Change, 2019; Rocha and Falduto, 2019; Coalition of Finance Ministers for Climate Action, 2020; Hans *et al.*, 2020; Institute, 2020)
	Sector-specific strategies, policies, instruments milestones and plans	(Vogt‑Schilb and Hallegatte, 2017; Levin *et al.*, 2018)
	Clear governance arrangements with a reflection on roles and responsibilities for national, subnational and local entities	(Levin *et al.*, 2018; World Resources Institute, 2018; Rocha and Falduto, 2019; Coalition of Finance Ministers for Climate Action, 2020)
Implementation framework	Bindingness and stringency of governance	(Oberthür, 2019)
	Strong/independent institutions leading implementation, independent expert institutions	(Recalde, 2016; Sartor *et al.*, 2017; Elliott *et al.*, 2019)
	Legislative framework	(Sartor *et al.*, 2017; Bennett, 2018; Haque and Ntim, 2018; Levin *et al.*, 2018; Eskander and Fankhauser, 2020)
	Iterative, inclusive stakeholder engagement, communication and learning	(Sartor *et al.*, 2017; De Pinto *et al.*, 2018; Levin *et al.*, 2018; World Resources Institute, 2018; IDB and DDPLAC, 2019; Investor Group on Climate Change, 2019; Rocha and Falduto, 2019; Waisman *et al.*, 2019; Coalition of Finance Ministers for Climate Action, 2020)
	Involvement of Governmental agencies and institutions. Definition of roles and responsibilities of institutions and stakeholders	(Levin *et al.*, 2018; Institute, 2020)
	Flexible policy framework, with periodic review and flexibility to adjust policy parameters	(World Resources Institute, 2019)
Monitoring, evaluation and review	Well defined monitoring plan with indicators and metrics for evaluation	(Levin *et al.*, 2018; Rocha and Falduto, 2019; Coalition of Finance Ministers for Climate Action, 2020; Institute, 2020)
	Defined processes and frequency for review	(Rocha and Falduto, 2019; DDPLAC Consortium, 2020; Hans *et al.*, 2020; Institute, 2020)

	Alignment of NDC and LTS through iterative revision cycles	(Hans *et al.*, 2020; Institute, 2020)
	Inclusion of long-term financial and investment vision, estimate of implementation cost of the strategy	(IDB and DDPLAC, 2019; Rocha and Falduto, 2019; Hans *et al.*, 2020)
Mobilisation of finance and technology development	Identify funding and financing mechanisms for required investments in institutions, infrastructure and technological innovation	(IDB and DDPLAC, 2019; Rocha and Falduto, 2019; Hans *et al.*, 2020)
Communication	Transparent, clear communication	World Resources Institute, 2018; Hans *et al.*, 2020)

3 Empirical evaluation of LTS

This section provides the results of a survey of existing LTS under each of the categories identified in the previous section, with examples from LTS and LTS-like processes and documents in specific countries and studies.

The goal in this compilation is neither completeness nor representativeness, but to highlight specific examples that shed light on options for best practice.

LTS development process: empirical evaluation

Build upon existing long-term strategies and institutional, legislative or governance frameworks
Holland's long-term strategy development largely built on recent strategy development processes for its Climate Act, Climate Plan and Climate Agreement. The Dutch Climate Act specifies an interim target for 2030, a final emissions target for 2050, and whilst focused on the 2030 target, specifically addresses steps that need to be taken between 2030 and 2050. The Act, which came into effect in July 2019, specifies a target of 49% reduction in emissions versus 1990. This was beyond the 40% reduction agreed at the EU-level at the time (the EU agreed to increase the ambition to 55% emission reduction by 2030 in December of 2020), in order to 'prevent the need for [..] abrupt measures after 2030 to achieve the 2050 target'. The Dutch Climate Plan outlines the key tenets of the climate policy to be implemented over the next 10 years, and was based heavily on the Climate Agreement, which was concluded between more than 100 civil society parties (both public and private). This agreement contains a package of measures that have the active support of as many contributing parties as possible and which will achieve the political reduction target of 49% by 2030. The parties to the Climate Agreement also formulated joint ambitions for the period until 2050.
Few countries detail the origins of the development process this explicitly. The German long-term strategy document refers to their government's coalition agreement of 2013, which agreed that "in the light of the European targets and the outcomes of the 2015 Climate Change Conference in Paris, in Germany we want to define an emissions reduction pathway with a final target of 80 to 95 percent lower greenhouse gas emissions compared to 1990 by 2050. We will augment this target with concrete measures, drawn up through a broad dialogue (Climate Action Plan)." New Zealand's process of developing its Climate Change Commission report, was based on an initial review of existing climate policies and ambition, the assessment that these were insufficient in meeting its net-zero emissions goal by 2050, and simultaneous the assessment that these are within reach with 'strong and decisive action now to drive low emissions technologies and behaviour change across all sectors', emphasizing that 2050 is not far away given the long-lived nature of vehicles, buildings, and infrastructure.
Whole of government approach for planning and designing LTS, independent lead institutions for supervising/managing/coordinating the design process
France's low-carbon strategy was initiated as an inter-ministerial work. This initial work was reviewed and revised based on extensive stakeholder consultations and was then followed up by a formal submission to several Government bodies, including, The Environmental Authority, The Expert Committee on Energy Transition, The High Council for Climate, the National Standards Evaluation Council, the Corsican assembly and the Overseas Collectives. The High Council on Climate, an independent authority, has oversight of the assessment of public policies in the area of climate change mitigation.

Stakeholder consultation
Mexico's LTS was developed by the Federal Ministry of Environment and Natural Resources (SEMARNAT) with the participation of the Institute of Ecology and Climate Change (INECC). The development received contributions from the Inter-Ministerial Commission on Climate Change (CICC), which is a body of 13 federal ministries as well as from bilateral meetings with federal government areas working in the field of climate change and the Climate Change Council. The LTS development sought stakeholder engagement at various levels. The LTS received inputs from advisory councils on sustainable development from all states. The LTS development also received inputs from experts from civil society, academia and the private sector. A nationwide online consultation process was also carried out to seek broader participation.
The US mid-century strategy (Obama Administration, submitted as LTS in 2016) organised stakeholder sessions with non-governmental and private sector organisations. The US strategy development was done in collaboration with other North American countries (Canada and Mexico) as well as other countries developing their mid-century strategies.
The French legislative framework on climate-change mandates public participation in the LTS review process (Article L. 100-1 A of the French Energy Code) (Ministry for the Ecological and Solidary Transition, 2020). The French Environmental Code mandates consultation with the High Council for Climate on compliance with set carbon-budgets and strategy implementation. The French LTS (SNBC) guidelines and baseline scenarios were developed with extensive stakeholder engagement processes at each policy development stage. Based on initial inter-ministerial work, the strategy was developed through iterative engagement with civil society representatives and the general public. Stakeholder consultations began with the SNBC's Information and Orientation Committee (CIO). This committee was formed with 120 members of the National Council for Ecological Transition, comprised of members for civil society, employee and employer representatives, consumer representatives, environmental NGOs, local authorities and parliamentarians. This was done in collaboration with related inter-ministerial services for alignment in strategy implementation within ministries. The CIO also collaborated in working groups with sectoral experts, including specialised professional federations and research institutes and academics. The general public participated in the process through an online questionnaire for guiding input on desired guidelines. The Multi-Annual Energy plan was also publicly debated with respect to climate change mitigation policy. The Expert Committee on Energy Transition also presented its compliance with set carbon budgets and the strategy's implementation. Finally, formal consultations on the draft strategy were held with the Environment Authority, the National Council on Energy Transition, The High Council for Climate, the National Council for the Evaluation of Standards, general public and the European Commission.

LTS design elements: empirical evaluation

Long-term vision and target

| Time-frame for strategy/consistency with the Paris agreement |
| --- |
| All long-term strategies submitted to UNFCCC have a time-frame until 2050 or earlier. China is the country with a net-zero emissions target later than 2050. It has submitted an NDC, but no formal long-term strategy to the UNFCCC. |
| **Long-term quantified outcome with coverage of gases and clear trajectory of emissions reduction with visibility on when emissions will peak** |
| The French low-carbon strategy is based on one baseline scenario. For this scenario, the strategy maps out an emissions profile until 2018 and a trajectory until 2050, based on recommended policies for each individual sector of the economy. These trajectories also show different reduction targets for these sectors |
| **Established link/synergy between mitigation and adaptation plan and development outcomes** |
| The French climate policy builds on the National Low Carbon Strategy and the National Climate Change Adaptation Plan. The low-carbon strategy provides guidelines for urban planning and development with a view to promote urban forms that are resilient to climate change. It also provides guidelines for developing tools for analysing potential changes in jobs and skills associated with energy and climate transition. In its sectoral analysis, it seeks to combine actions for mitigation, climate change adaptation and risk management. |

Mitigation elements

Clear description of how long term strategy aligns with Paris Agreement commitments and targets including when CO2 neutrality and net-GHG neutrality will be achieved
The UK's Committee on Climate Change's recommendation for a net-zero GHG target by 2050 presents as assessment of the implications of the Paris Agreement on the UK emission reduction targets, considerations of equity, the UK's capability for achieving higher ambitions.
Alignment of NDCs with LTS, backcasting for interim targets using long-term benchmarks
The UK's 2008 Climate Change Act introduced carbon budgets, which provide a statutory cap on total greenhouse gas emissions for a five-yearly period. These budgets are set 12 years in advance, as per the advice of the UK's independent advisory body, the Climate Change Committee (Fankhauser, 2020). The carbon budget is backcasted from the long-term 2050 target. The sixth carbon budget, released in December 2020, raised the UK's climate ambitions in line with the UK's net-zero target announced in 2019 (Committee on Climate Change, 2020).

Similarly, France's carbon budgets are set for a five year period based on the long-term trajectory. France's next carbon budget will be based on the revised National low carbon strategy, which aims for a net-zero target by 2050 |

Modelling and scenario development

Use of national modelling with quantified scenarios and indicators or use of global models with local detail, including a description of qualitative analysis undertaken for setting mitigation target
Mexico's economic modelling exercise uses the Massachusetts Institute of Technology Economic Projection and Policy Analysis (EPPA) model, calibrated using Mexico-specific information. The calibrated model evaluates two policy scenarios with different emission reduction targets.
The US mid-century strategy (submitted as LTS to UNFCCC in 2016, under the Obama administration) is based on original analysis and modelling conducted for analysing low-emissions pathways for the US. The strategy considers economy wide modelling that includes all sources and sinks of greenhouse gas emissions, including more granular sector-specific models. This original modelling-based analysis was informed by peer-reviewed academic studies and studies conducted by private, public and non-profit organisations that have analysed decarbonisation scenarios for the US. In addition, feedback received from stakeholder consultations and learnings from collaborative efforts with other countries that were developing long-term strategies, also informed the strategy development.
Australia's Climate Change Authority in its 2014 report set out a principled method for determining a national share in a global effort, and provided extensive economic modelling based analysis of global and national emissions trajectories including international flexibility mechanisms (Climate Change Authority, 2014).
Clear communication of methodology used for projecting scenarios with information on type and name of model. Clear identification and communication of assumptions
New Zealand's Climate Change Committee's draft advice includes an accompanying evidence document which outlines the 1) methodology used for developing scenarios for emissions reduction, 2) assumptions used in building different emission scenarios 3) objectives and principles underlying the accounting choices used for calculating emission budgets 4) detailed information on the type and name of the custom model used for the analysis
The US mid-century strategy (submitted as LTS to UNFCCC in 2016, under the Obama administration) includes information on all modelling tools and data sources included in analysis. It includes information on models used for specific sectors. It also cites the source of greenhouse gas inventory data.
Use of a combination of different modelling approaches and tools, and of quantitative and qualitative approaches
Scenario development under the French low-carbon strategy was carried out with regular stakeholder consultation. Initially, the Information and Orientation Committee (CIO), made up of members from the National Council for Ecological Transition, met several times to of the strategy review process, which included validation of the baseline scenario assumptions. Additionally, working groups, composed of members of the CIO and sectoral experts met several times to provide their expertise on the definition of assumptions. At the end of the revision process, formal consultations on the strategy were held with the Environmental Authority, the National Council of Energy Transition, the High Council for Climate, the National Council of the Evaluation of Standards, the Corsican Assembly, general public, the European Commission and French Overseas Territories.
NZ's Climate Change Commission's draft report develops assumptions based on available evidence and stakeholder engagement with experts and relevant stakeholders.

The Deep Decarbonization Pathways Project (Bataille *et al.*, 2016; Sachs, Schmidt-Traub and Williams, 2016) employed a multitude of engineering as well as economic modelling approaches, including 'bottom-up' sectoral modelling in parallel with 'top-down' aggregate modelling. It was undertaken as coordinated but independent studies by universities, research institutes and think tanks in a number of countries ahead of the Paris Agreement.

Policy pathways under multiple alternative futures. Pathways with different emission reduction goals or different scenarios that lead to the same target

The US mid-century strategy (submitted as LTS to UNFCCC in 2016, under the Obama administration) evaluates emission scenarios with an emissions reduction target as well as scenarios that result in different emissions targets. The scenarios differ in regard to their reliance on key low-carbon technologies and decarbonisation strategies, which will result in differentiated implications for emissions reduction, societal priorities, the cost of decarbonisation, environmental impacts, energy security and safety (White House, 2016)

The UK's Committee on Climate Change report on recommendations for a 2050 GHG targets factors in uncertainties on economic, demographic, social and behavioural factors that could influence future policy pathways. It also considers uncertainties around development, deployment, costs and emission reduction potential of low-emission technologies. The report adopts a conservative approach to minimise the risk of advised target being unachievable and presents three scenarios that lead to a net-zero emission scenario. It also presents alternative policy pathways within sectors for achieving the same emission reduction target.

The Princeton University *Net Zero America* study (Larson *et al.*, 2020) models five distinct technology pathways without judgment of which is preferable or more likely. It identifies multiple plausiable and affortable trajectories for how defined outcomes could be achieved at a given future level of spending on the energy system.

Bottom-up modelling approach used in the UK Committee on Climate Change report for its Net-Zero report
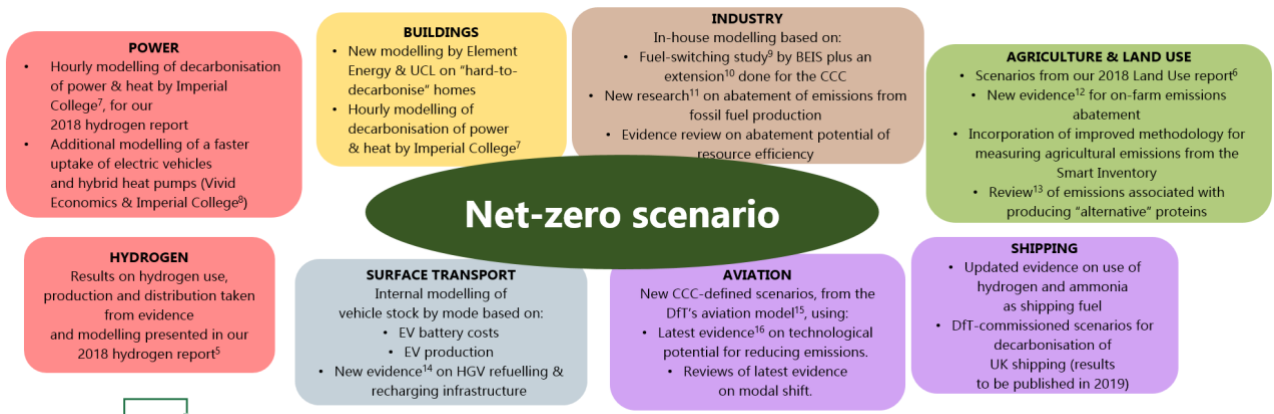
Source: (Committee on Climate Change, 2019a)

Transformative change

Recognition of the need for early action to meet long-term targets
Holland's long-term strategy incorporates a ambitious interim target for 2030, with the stated purpose of 'preventing the need for [..] abrupt measures after 2030 to achieve the 2050 target'. Its LTS, and related Climate Plan and Climate Agreement both focus on 2030 targets but recognize the final goal of full decarbonisation by 2050, and discuss policy and technology options to get there.

Whole systems reconfiguration incl. plans for each technology or sector
New Zealand's Climate Change Commission's draft advice to the Government analyses all sectors of the economy, recommending policy measures for emission reduction. France's low-carbon strategy presents sectoral assessments and strategies for all sectors of the economy

Managed phase-out fossil fuel sectors and plans for a Just Transition
Japan's LTS plans to engage the government, local authorities and companies to provide vocational training to the workforce, provide support for diversification of business operations, and invite new businesses and support for the placement of the labour force (Government of Japan, 2019).
South Africa's LTS recognises that transition to a low-carbon economy and society will have uneven socio-economic impacts. The LTS states that the National Planning Commission is developing decarbonisation pathways in key areas of land water and energy through a consultative and bottom-up process. The South African Government is also developing policy instruments, such as The National Employment Vulnerability Assessment and Sector Jobs Resilience Plans which will address sectoral employment characteristics and job losses and investigate future opportunities in a decarbonised economy.
Germany's coal phase-out Act is accompanied by the Structural Support for Coal Regions Act, which recognises socio-economic changes associated with the coal-phase out. The Act provides coal regions with financial aid for making investments for dealing with structural changes associated with the transition, secure employment, improvement or expansion of highway and rail infrastructure and creation of 5000 additional jobs in federal agencies in the coal region (Gesley, 2020).
The European Commission's Just Transition Mechanism aims to address the socio-economic impacts of transition to a low-carbon economy by focusing on most vulnerable coal and carbon-intensive regions. Under this mechanism, European member states are required to prepare Just Transition Plans that cover the period until 2030 for their territories. Once approved by the European Commission, member states will receive support from: the European Commission's Just Transition Fund which will provide grants, the European Investment Bank' public sector loan facility which will support decarbonisation initiatives by public sector authorities in coal and carbon-intensive regions and a scheme under InvestEU which will crowd in private investment (European Commission, no date b, no date a).

Adaptation planning

Integration/synergy of national adaptation plans to long-term strategy

Mexico's General Law on Climate Change incorporates an approach that integrates adaptation and mitigation actions. The law requires mitigation and adaptation policies to be updated every 10 and 6 years, respectively. The federal Special Climate Change Program has been identified to define objectives and actions for mitigation and adaptation planning every six years. The LTS also commits to updating the strategy as per provisions agreed under UNFCCC (Ministry of Environment and Natural Resources, 2016). Mexico's LTS builds on vulnerability assessments carried out for several climate change scenarios, which identified municipalities in Mexico that were most vulnerable to climate change.

The French low-carbon strategy builds upon the National Climate Change Adaptation Plan and it is a complement to it under the French Environmental Code (Ministry for the Ecological and Solidary Transition, 2020). Under the strategy, The High Council for Climate will report annually on the implementation and effectiveness of GHG reducing federal/local policies for mitigation as well as adaptation.

Goals for enhancing adaptive capacity, sectoral vulnerability assessment, increase resilience and reduce vulnerability across sectors

Mexico's LTS includes an adaptation plan which, based on a vulnerability assessment, identifies priority actions to build social resilience while reducing vulnerability factors, measures to protect strategic infrastructure and production systems and ecosystems based adaptation (Ministry of Environment and Natural Resources, 2016). The strategy also includes cross-cutting policies across mitigation and adaptation measures.

Development objectives and SDGs

Integration of LTS with Sustainable Development Goals

Finland's LTS uses a modelling exercise to assess the national economic impact from different technological choices and emission reduction trajectories. The LTS also includes a brief description of the scenario modelling process.

Japan's LTS states that the government will aim to create a 'Circular and Ecological Economy' that will encourage regional communities to sustainably use regional resources, promote local decarbonisation and build self-reliance while building broader networks for enhanced decarbonisation.

Indonesia's low-carbon development initiative (Indonesia's Ministry of National Development Planning, 2019) carries out scenario-based modelling to estimate the impact of low carbon policies on economic, social, environmental and climate-related variables. It also produces empirical estimates of projected impact on economic growth, employment, poverty reduction, air and water pollution and biodiversity.

Clearly quantified assessment of gains in terms of economic growth employment etc.

California's Climate Change Scoping Plan for its 2030 target included consideration of development objectives and co-benefits in its criteria for evaluating potential policies (California Air Resources Board, 2017). The strategy presents an evaluation of envisaged policies and measures by estimating air pollution reduction, avoiding economic damage, health impacts of pollution reduction and active transportation, economic impacts, and estimated cost of planned measures and macroeconomic impacts such as GDP and employment and personal income. It also estimates regional impacts on disadvantaged communities of the scoping plan using a model.

LTS implementation elements: empirical evaluation

Implementation pathway

Linkage between NDCs and long-term target/Milestone targets
Germany's long term strategy, Climate Action Plan 2050, is reviewed and updated in accordance with the five-year review cycle for NDCs (Federal Ministry for the Environment Nature Conservation Building and Nuclear Safety (BMUB), 2016). Germany's LTS states that intermediate targets and milestones will be continuously reviewed to ensure their consistency with set emission reduction targets for greenhouse gases.
Mexico's LTS factors NDC goals in its 2050 emissions trajectory (Ministry of Environment and Natural Resources, 2016)
Japan's LTS establishes a review of policy measures with reference to situations every six years (Government of Japan, 2019)
Sweden's climate policy framework (Government Offices of Sweden, no date), adopted in 2017, sets out an implementation pathway for the Paris Agreement under which Sweden aims to have net-zero GHG emissions by 2045. The Climate Act establishes that the 1) Government's climate policy needs to be based on climate goals 2) a climate report to be submitted every year in the budget bill and 3) a climate policy action plan drawn up by the government, every fourth year, describing how climate goals will be achieved.
Under France's National Low Carbon Strategy (Ministry for the Ecological and Solidary Transition, 2020), revised in 2018-2019, short and medium term emission trajectory is defined by carbon budgets for 2019-2023, 2024-2028, 2029-2033.
Indonesia's Low Carbon Development Initiative (Indonesia's Ministry of National Development Planning, 2019) for integrating climate action into the country's development agenda builds upon its NDC targets.
Inclusion of all sectors of the economy, opportunities and synergies between different sectors, identification of key sectors that drive emissions, sector-specific strategies, policies, instruments milestones and plans
While the UK's Climate Change Act excludes international aviation and shipping in the UK's emissions reduction targets, it states that the Government must take these emissions into account in setting carbon budgets. As directed by the Committee on Climate Change, the UK long-term strategy (submitted to UNFCCC with a long-term target of 80% GHG reduction by 2050 relative to 1990 levels) has included emissions amounting to 41 MtCO2e in 2050, accounting for international aviation and shipping emissions. As per the long-term strategy, the carbon budget puts the UK on a consistent trajectory with their 2050 emissions including emissions from these sectors (HM Government, 2017).   The UK's independent Committee on Climate Change (CCC) has published a reassessment of the UK's long-term emission reduction targets, as per requests from the Governments of the UK, Scotland and Wales. The CCC's has recommended a net-zero greenhouse gas target by 2050 for the UK, a net-zero greenhouse gas target by 2045 for Scotland and a 95% reduction of greenhouse gas target by 2050 for Wales (Committee on Climate Change, 2019b). This net-zero target includes fluorinated gases. These targets are supported by a detailed analysis for each sector of the economy. For each sector, the analysis presents an assessment of the current level of emissions with a breakdown of different sources of emissions. The CCC analysis presents decarbonisation options for each sector and an assessment of the option's availability

and scale. Using this information, the CCC identifies UK-wide emission reduction pathways, by sector, for achieving net-zero domestic emissions. It also presents measures for each sector and its associated costs, co-benefits, challenges and identifies urgent actions to be prioritised. Using this sectoral analysis, the CCC presents economy-wide scenarios using a bottom-up approach that considers the interactions between individual sources of emissions. The scenario analysis also presents the rate at which technologies interim targets with timelines and key policy implications for each sector.

France's low carbon strategy recognises that a carbon-neutral economy would require transformational change and therefore aims to integrate climate commitments at all levels of governance in each sector and policy development. The low-carbon strategy provides guidelines for addressing cross-sectoral issues, such as a reduction in the carbon footprint of consumption, economic policy, R&D policy, urban planning and development, citizens' education and awareness and employment, skills, qualifications and occupational training as well as for decarbonising sectors (agriculture, transport etc.) of the economy. For each sector and all cross-sectoral issues, the low-carbon strategy maps out a strategy, provides guidelines on achieving mapped strategy and identifies potential areas of concern. In addition, the strategy identifies metrics that will be monitored for each guideline in the strategy.

Linkages with existing policies and regulation

The UK's Clean Growth Strategy has its existing policies as the basis for the UK's emission projections and builds scenarios based on the combination of existing and new measures (HM Government, 2017)

France's National Low Carbon Strategy (SNBC) has guidelines to ensure that its objectives and guidelines are integrated into all national public policies (Ministry for the Ecological and Solidary Transition, 2020). It also has guidelines for monitoring and evaluating the integration of SNBC in all public policy documents

Integration of national energy/climate plan

Finland's LTS builds upon its National Energy and Climate Strategy and the Medium-term Climate Change Policy Plan. The allocation of emission reductions and policy measures for economic sectors will be ascertained under its Climate and Energy Strategy and Medium-term Climate Change Policy Plan in 2020-2021.

South Africa's LTS builds on the country's National Development Plan, The National Climate Change Response policy The Climate Change Bill (forthcoming) as well as strategies, policies and plans developed for sectoral transition to low-emissions. (Environmental Affairs Republic of South Africa, 2020).

France's National Energy and Climate Plan for 2021-2030, submitted as per EU 2018/1999 regulation (European Commission, 2020), is guided by the Multiannual Energy Plan (10-year outlook) and France's National Low Carbon Strategy which aims for carbon neutrality by 2050

Synergies with sub-national plans

South Africa's LTS aims to align sub-national efforts for mitigation, adaptation and resilience through The Climate Change Act. Under this Act, provincial and district municipalities intergovernmental forums will be required to serve as Provincial forums where these forums will be responsible for coordinating climate change response actions and reporting progress for their jurisdictions. The Act also requires provincial and local authorities to develop and implement a climate change response implementation, which is required to be updated every 5 years (Environmental Affairs Republic of South Africa, 2020).

Under the pan Canadian Framework for clean growth and climate change, Canadian First Ministers and Indigenous leaders agreed to build on commitments and actions already taken by provinces and territories for meeting and exceeding Canada's emission reduction targets (*Pan-Candian Framework on Clean Growth and Climate Change*, 2016)

Implementation framework

Clear governance arrangements with a reflection on roles and responsibilities for national, subnational and local entities, bindingness and stringency of governance
Mexico's General Law on Climate Change guides its institutional and implementation framework for its climate policy with a mandate for the Federal Government to develop and guide implementation. It identifies the definition of the roles of federal and sub-national governments. It also establishes Mexico's National Climate Change System to coordinate policy at the national and sub-national level. This framework created two federal agencies, the Interministerial Commission on Climate Change (CICC) and the National Institute for Ecology and Climate Change (INECC). The Federal Congress, provincial governments and national associations of municipal officials, all included in the National Climate Change System, are tasked with coordinating action at the sub-national level. This framework also created the Climate Change Council (C3) as an advisory body for the government.
The legislative and regulatory context for France's National Low Carbon Strategy lends stringency of governance for its implementation. Article L.222-1 B of the French Environmental code sets the low-carbon strategy content by decree. It mandates the course of mitigation policies for the short and medium-term to be consistent with the French Energy Code (Ministry for the Ecological and Solidary Transition, 2020). It accounts for particularities of specific sectors of the economy with a low potential for mitigation. The decree also defines the carbon budget for each period with an associated ceiling on greenhouse gas emissions. For implementation, Article L. 222-1 B of the French Environment Code places adoption obligations on provincial and local authorities and their respective public institutions. For the integration of low-carbon vision into its investment policy, Article D 533-533-16-1 of the French Monetary and Financial Code mandates asset management companies to provide information relating to the consideration of the social, environmental and governance quality criteria (Ministry for the Ecological and Solidary Transition, 2020). The legislation also sets, the assessment framework for compliance with carbon budgets, time-frame for strategy revision and enactment of a new carbon budget, public participation in the review and the roles and responsibilities for The High Council for Climate. France's low carbon strategy aims to integrate climate issues at the national and territorial level. At the federal level, the strategy identifies national agencies tasked with ensuring climate change mitigation is a priority for public policy design and implementation. The Senior Sustainable Development Officials and the Ministry of Environment are responsible for coordinating and evaluating public policies in each ministry on sustainable development criteria. The National Council of Ecological Transition, a forum for dialogue representing parliamentarians, local authorities, environmental protection associations, corporates, trade unions, and civil society, is also consulted for an opinion on the ecological transition policy. France has also established The High Council of Climate, an independent body tasked with assessing state and community public policies for climate change mitigation. The High Council for Climate will evaluate current and future policy laws on greenhouse gas abatement one-year post-implementation as per its mandate. At the territorial level, localisation of the low carbon strategy will be through regional schemes. Inter-municipal authorities will develop territorial climate-air-energy plans, which will describe the emissions trajectory and associated short-term actions. The strategy also identifies indicators for monitoring compliance at the national and territorial level.

Independent institutions leading implementation, independent expert institutions
Sweden's climate policy framework established the Climate Policy Council, which is an independent, interdisciplinary expert body. The Climate Policy Council is required to provide assessments on government policy compliance with national climate targets. The Climate Policy Council is also required to submit an annual progress report to the government on current emissions trends and the assessment of work done to address climate change. The Climate Policy Council is also required to submit an assessment of the Government's Climate Policy Action Plan (Swedish Environmental Protection Agency, 2020).
Denmark's Climate Law created an independent academic-based council on climate change in 2015, tasked with contributing to public discussions on Danish climate policy and publishing their recommendations to the Government (Danish Energy Agency, no date).

Legislative framework
The UK's Climate Change Act, passed in 2008, established a legally binding emissions reduction target for its Clean Growth Strategy (submitted to UNFCCC as LTS) California's economy wide carbon neutrality goal by 2045 was passed as an executive order in 2018 (Executive Department State of California, 2018)
Under New Zealand's Climate Change Response (Zero Carbon) Amendment Bill, the Climate Change Commission will recommend milestone emission budgets for 2022-2025, 2026-2030 and 2031-2035 (Ministry for the Environment, 2019).
The Danish Climate Act sets a net-zero target by 2050. The Climate Act also contains a mechanism by which the government is mandated to set a legally binding target every five years. The Act also mandates the development of annual Climate Action plans that outline sectoral policies for emissions reduction (Danish Ministry of Climate Energy and Utilities, 2019). The law mandates annual national climate targets and an energy policy report covering the current status of greenhouse gas emissions and compliance with international obligations to be submitted by the government to the Parliament. The law also created an independent academic-based council on climate change in 2015, tasked with contributing to public discussions on Danish climate policy and publishing their recommendations to the Government (Danish Energy Agency, no date).
The UK's net zero target by 2050 was legislated as an amendment to its Climate Change Act 2008 (UK Parliament, 2019a). Under the Climate Change Act 2008, the government must set five-yearly carbon budgets from 2008-2050, twelve years in advance (UK Parliament, 2019b). The Act set a governance framework by creating an independent, statutory adviser, The Climate Change Committee (CCC), which is responsible for conducting independent analysis, providing advice on setting and meeting carbon budgets, monitoring emission reduction progress and engage with stakeholders (Climate Change Committee, no date).
In November 2020, Canada introduced Bill C-12 (House of Commons of Canada, 2020), which aims to legally bind the federal government to a process for achieving net-zero emissions by 2050. This legislation will set five-year rolling emissions reduction targets for period 2030-2050 with the requirement for an independent third-party review every five years by the Commissioner of the Environment and Sustainable Development reporting on the federal government's implementation of measures for climate change mitigation. This legislation will also establish an advisory body that will provide independent advice to the federal government on measures and sectoral policies required for achieving Canada's greenhouse gas emissions reduction targets.
The German coal-exit strategy is backed by a legislative package, based on recommendations from the Commission on Growth, Structural Change and Employment (aka 'Coal Commission'). This legislative package includes the Act to reduce and end coal powered energy by 2038, amendments in the German Renewable Energy Sources Act which raise the goal for percentage

of renewables in the energy mix to 65% by 2030 and the Structural Support for Coal Regions Act which targets the regional coal economies that will undergo socio-economic changes due to this transition (Gesley, 2020).

Iterative, inclusive stakeholder engagement, communication and learning

The German LTS states that revisions to the Climate Action Plan will include extensive stakeholder engagement from provincial governments, local authorities, the private sector, civil society and the public (Federal Ministry for the Environment Nature Conservation Building and Nuclear Safety (BMUB), 2016). The German Government created the Climate Action Alliance in 2015, consisting of representatives from civil society, provincial governments and local authorities, for implementation of its Climate Action Plan. The LTS states that this alliance will be continued for engagement and support the implementation of its 2050 strategy. The LTS also plans regular evaluation of stakeholder engagement processes for improving the processes.

Flexible policy framework, with periodic review and flexibility to adjust policy parameters

The German LTS will be reviewed and updated as per the NDC review cycles. During these revisions, technological advancement, the latest scientific information and socio-economic changes will guide the adjustment and adaptation of planned policy pathways and measures.

The French national strategy uses a set of monitoring indicators for assessing the implementation of proposed measures. The strategy allows for evolution/addition of these indicators in future revisions.

Mexico's National System for Climate Change, adapted from (Ministry of Environment and Natural Resources, 2016)

| Interministerial Commission for Climate Change	Climate Change Council	Federal Congress	National Association of Municipal Officials	States	National Institute of Ecology and Climate Change
• Interministerial body • Formulate and implement national policies on mitigation and adaptation • Mainstream climate action in sectoral programs and actions • Develop criteria for cross-cutting public climate change policie • Participate in elaboration and implemnetation of the Special Climate Change Program	• Permanent consultative body • Expert group from social, academic and private sectors • Provide advise and recommend studies, policies, actions and goals for climate mitigation • Promote social participation through public consultation process	• Comprised of the the senate and the Chamber of Deputies • Responsibilities of proposing, discussing and approving laws on GHG reduction, climate change mitigation and adaptation • The Special Commission Climate Change responsible for this task in the senate • The Climate Chnage Commission responsible for this task in the Chamber of Deputies	• Composed of national confederation of municipalities, association of local authorities and the national association of Mayors • Develop, conduct and evaluate municipal climate change policy • Foster scientific and technological research • Develop strategies, programs and projects on climate change mitigation • Process and integrate municipal level rmissions date for incorporation into the National Emissions Inventory	• Develop, implement and evaluate state-level climate change mitigation and adaptation policy and programs • Foster scientific and technological research and the development, transfer and deployment of technologies, equipment and processes • Process and integrate state-level emissions data for incorporation into the National Emissions Inventory	• Coordinate scientific and technological research collaborating with national/global public/private academic and research institutes • carry out prospective sector-analysis and elaborate climate change strategies, plans, programs etc. • Coordinate and evaluate climate policy with participation of civil society advisors

Monitoring, evaluation and review

Involvement of agencies and institutions, definition of roles and responsibilities of institutions and stakeholders
The Korean LTS presents an institutional framework for the assessment of its NDC goals. Under this mechanism, the Central Government ministries and agencies responsible for its nine sectors are responsible for setting targets and indicators of assessment and collecting information on each sector's associated budgets and policies. These Central Government ministries and agencies are also responsible for collecting and submitting annual assessment data to the Greenhouse Gas Inventory and Research Centre (GIR). Based on submitted annual assessment data, the GIR then prepares a synthesis report, in collaboration with other national research institutes and an expert working group, on implementation assessment (Government of the Republic of Korea, 2020). The Presidential Committee on Green Growth, an inter-ministerial institution composed of public officials and experts (United Nations ESCAP Korea International Cooperation Agency, 2012), is responsible for overseeing this implementation assessment and offering policy advice the monitoring and review data.
Well defined monitoring plan with indicators and metrics for review, defined processes and frequency of review
The Korean LTS's monitoring and assessment plan for NDC achievement includes preparing a synthesis report for reviewing mitigation policy outcomes in nine sectors of its economy. It identifies 81 indicators across these nine sectors used to assess implementation outcomes. It identifies individual ministries responsible for collecting information on their respective targets, budgets and policies identified for corresponding assessment indicators. The Greenhouse Gas Inventory and Research Centre (GIR) then prepares a synthesis report that also includes estimates of potential emissions (Government of the Republic of Korea, 2020).

The French low carbon strategy presents a detailed monitoring and evaluation plan for assessing compliance. It identifies qualitative and quantitative indicators for evaluating the degree of inclusion of strategy guidelines in public policies, environmental assessment, implementation of cross-cutting and sectoral guidelines, establishing context indicators (socio-economic, climatic, environmental and technological) as well as indicators on national objectives (on carbon footprint, national and sectoral emissions and sectoral energy consumption). The list of monitoring indicators was developed with stakeholders participating in the Strategy's Information and Orientation Committee and is based on existing statistical tools. Data on these indicators is made public and is published annually. Thorough monitoring of these indicators is to be conducted every two years. A retrospective evaluation is mandatory every fourth year after a low carbon strategy enactment which assesses compliance with carbon budgets, sectoral pathways, degree of inclusion of strategy guidelines in public policies and deviation from target scenario. This evaluation report will is presented to The High Council for Climate and its comments are taken into account, after which the report is made available publicly. The French Energy Code requires a revision of the low-carbon strategy every five years through a participatory process involving Government institutions, independent institutions and other stakeholders. The revised strategy and revised carbon budget is then submitted to the National Council for Ecological Transition and The High Council for feedback. Subsequently, a decree will be enacted which will set the low-carbon strategy and carbon budgets. Finally, the revised strategy, complete carbon budget quantitative assessment and assessment of results achieved over the last evaluation period will be submitted to Parliament.

Alignment of NDC and LTS through iterative revision cycles

The German Government's LTS states that it will be reviewed and updated as per the NDC review cycle. As per the LTS, short and medium targets and milestones, policy pathways and associated measures will be continuously monitored and reviewed for ensuring consistency with associated targets. This will also allow consistency with the Paris Agreement, which requires a progressive raise in climate ambition.

Korea's NDC implementation assessment mechanism, adapted from (Government of the Republic of Korea, 2020)
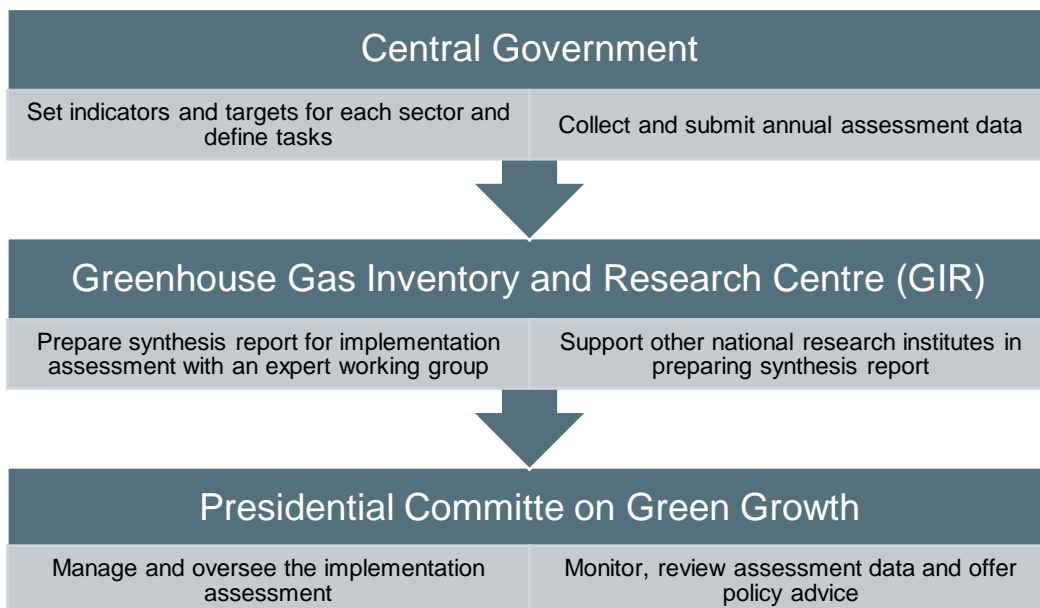
Mobilisation of finance and technology development

Reflection of improved understanding on mobilisation of domestic and international finance and technology resources over time, inclusion of long-term financial and investment vision
The Austrian LTS commissioned scientific analyses to estimate sectoral investment requirements. The results of these analyses will be made public in the near future (Federal Ministry Republic of Austria Sustainability and Tourism, 2019). The Austrian LTS recognises that public funds alone will be insufficient for envisaged investments. The Austrian Federal Ministry of Finance and the Federal Ministry for Sustainability and Tourism have set up a Focal Group on Green Finance. The strategy states that an Austrian Green Finance Agenda will be established in collaboration with key financial market participants. The LTS also states that a continued collaboration between public and private institutions is being considered, which will enable a discussion and joint action on envisaged long-term pathways and measures.
The Japanese LTS states that the Government aims to mainstream Environmental, Social and Governance investment framework within the private sector for encouraging investment in climate change related solutions and innovations. The Japanese Government is also taking initiatives, such as the formulation of Green Bond Guidelines and the establishment of the Green Bond Issuance Promotion Platform, for supporting the issuance of green bonds (Government of Japan, 2019). The Government has also formulated Guidelines for Climate-Related financial disclosures (TCFD Guidance) for climate-related environmental information disclosure by companies. To encourage transparency for investors, the Government has developed a platform where companies can disclose environmental information. This database will allow investors to compare environmental information disclosed by companies. The Government aims to mainstream TTCFD Guidance in the investment framework by encouraging dialogue between the industry and financial sector domestically through its TCFD Consortium and globally by conducting summits for international collaboration. To encourage technology development, Japan has formulated its Progressive Environment Innovation Strategy (Yuji, 2020). This strategy estimates potential emissions reductions from sectoral low-carbon transitions. It further describes Innovation Action Plans that identify 16 technological challenges with associated cost targets. It also presents Innovation Action Plans for establishment of innovative technologies by 2050 with associated cost targets, potential GHG reduction, potential R&D strategy and measures for scale-up of technology. As part of this strategy, a Global Zero Emission Research Centre has been established under the Department of Energy and Environment (Department of Energy and Environment Government of Japan, 2020).
The French LTS includes a section on Research and Innovation Policy for achieving technological breakthroughs, innovation and the adaptation of production and consumption patterns. It identifies sectors and areas for research and innovation. It builds upon France's existing National Research Strategy and the National Energy Research Strategy. Implementation of the strategy is monitored with indicators such as related patents for mitigating greenhouse gas emissions and public expenditure on R&D in the budget document.
The Finnish LTS estimates investments required for climate-neutrality in the industry sector based on a survey published by the Confederation of Finnish Industries and some other sources.

Communication

Transparency, clear communication
New Zealand's current emissions target includes split targets with a net-zero emissions target of all gases other than biogenic methane by 2050 and a 24-47% reduction below 2017 biogenic methane levels by 2050 target, including a 10% reduction below 2017 biogenic methane emissions by 2030 (Ministry for the Environment, no date). New Zealand has established an independent crown entity, the Climate Change Commission, under its Climate Change Response Act (2002). The Climate Change Commission has been tasked with several statutory functions, including, providing independent expert advice to the Government on mitigating climate change and adapting to the effects of climate change, and monitoring and reviewing the Government's progress towards its emission reduction and adaptation goals (New Zealand Climate Change Commission, 2020). In 2021, the Climate Change Commission released its draft report with advice on its first three five-yearly carbon budgets for meeting NZ's 2030 and 2050 domestic emissions targets, and policy-directives that should be included in the Government's first emission reduction plan. The draft report addresses the split targets separately. The draft report clearly states the scope and terms of reference under the Climate Change Response Act (2002) for reductions in biogenic methane. The draft report states that the Climate Change Commission's mandate does not include providing advice on a reduction target for biogenic methane for biogenic methane, keeping consistency with the Climate Change Response Act which limits the circumstances for reviewing the target.

4 Conclusion

Long-term emissions strategies are an important tool to translate long-term emissions goals into possible trajectories and menus of actions. They can support decisions by governments and businesses.

This paper provides a conceptual synthesis and empirical analysis of development of LTS and lays out how a best-practice LTS enables consideration of the full range of considerations, options and pathways. From our empirical analysis of the multitude of approaches taken to long-term emissions strategies (LTS) in different countries and jurisdiction, and from insights in the research literature, a number of elements of best practice can be identified.

For the *process* of creating an LTS, they include to build on existing related strategies and to align with institutional, legislative, or governance frameworks; to employ 'whole of government' approaches to planning and designing LTS; for independent institutions to take a prominent role in the process; to facilitate cooperation beyond government agencies in creating an LTS; and to make broad-based stakeholder consultation an integral part of the process.

Necessary or desirable *design elements* of an LTS include a long-term vision and target, including how trajectories align with development outcomes, Paris Agreement commitments and other emissions goal; roadmaps for integration of LTS with broader economic and societal objectives, especially with regard to potential economic opportunities at a national and sub-national level, economic transition and sustainable development; analysis of a comprehensive range of elements of climate change mitigation elements, taking into account a broad range of benefits and costs, and

representing deep uncertainties about future technological and economic parameters through multiple possible pathways; modelling and scenario development that combines quantitative and qualitative elements, multiple models and pathways, identifies 'critical path' decisions and considers decision-making under deep uncertainty; climate change adaptation planning based on broad-based sectoral vulnerability assessments; and recognition of the possibility of or need for transformational change, including in specific technologies as well as system-wide interactions.

Best practice *implementation elements* of an LTS include the identification of feasible implementation pathways, including in governance and policy and in sectoral and sub-national dimensions; a robust implementation governance framework, including strong institutions, clarity about respective roles, a flexible policy framework, extensive and sustained stakeholder engagement, mobilisation of finance and technology development; clear, consistent and extensive public communication; and well defined plans for monitoring, evaluation and review, including the capacity to refine implementation plans on the basis of experience and new evidence.

Not all of these elements will be relevant or possible for each LTS, and the relative importance placed on different elements will differ depending on the specific context in which an LTS is developed, and the objectives as defined by governments. However, the stocktake and synthesis provided here can provides a benchmark that national and sub-national governments can apply in designing, implementing or refining their LTS.

Taken together, the best-practice elements can be considered a benchmark for national or sub-national LTS frameworks. Elements would be expected to be tailored according to specific context and objectives, and further evidence will emerge as LTS frameworks continue to be refined.

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