International Renewable Energy Agency

LONG-TERM ENERGY SCENARIOS AND LOW-EMISSION DEVELOPMENT STRATEGIES

Stocktaking and alignment

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Abbreviations

CCUS	carbon capture, utilisation and storage
CDR	carbon dioxide removal
EFOM	Energy Flow Optimisation Model
EU	European Union
GHG	greenhouse gas
GW	gigawatt
IRENA	International Renewable Energy Agency
LEAP	Low Emissions Analysis Platform
LTES	long-term energy scenarios
LT-LEDS	long term low greenhouse gas emission strategy
LULUCF	land use, land-use change and forestry
MARKAL	market allocation
MESSAGE	Model for Energy Supply System Alternatives and their General Environmental impacts
MW	megawatt
NDC	Nationally Determined Contribution
NECP	National Energy and Climate Plan
PV	photovoltaic
TIMES	The Integrated MARKAL-EFOM System
T&D	transmission and distribution
UNFCCC	United Nations Framework Convention on Climate Change

SUMMARY AND KEY FINDINGS

Long-term energy scenarios (LTES) are a vital planning tool for guiding the transition to a clean, sustainable and increasingly renewable-based energy system. Following COP21 in Paris in 2015, countries have also begun to develop long-term low [greenhouse gas] emission development strategies (LT-LEDS), to explore the challenges and opportunities associated with the structural transformations needed to reach carbon neutrality and meet the targets of the Paris Agreement. As of October 2022, 36 out of the 53 LT-LEDS submitted so far to the Secretariat to the United Nations Framework Convention on Climate Change (UNFCCC) have featured quantitative scenarios as their main tool to outline alternative pathways and targets, and to assess the short- and medium-term policies needed to reach their long-term targets.

This report explores the landscape of scenarios in both LTES documents and LT-LEDS. It provides an initial qualitative overview of two main characteristics of scenarios featured in 24 LTES documents and 36 scenario-based LT-LEDS from 45 countries: first, the institutional and governance framework in which LTES and scenario-based LT-LEDS publications are developed, including the level of institutional co-ordination, stakeholder consultation, type of publication and highlights from these publications; and second, the coverage of energy transition elements assessed in these publications. The development of LTES has a long history in many countries and they have primarily been used to guide long-term energy policies. In recent years, LTES have increasingly incorporated CO_2 emissions and mitigation into their scope. In contrast, LT-LEDS are a relatively new part of a national planning process introduced by the UNFCCC that focuses on achieving a climate neutral economy, with energy as a key component. While LTES and LT-LEDS have originated from different processes, the increasing importance of emission mitigation in the LTES process and the central role of the energy sector in achieving economy-wide climate neutrality in the LT-LEDS process has led to efforts to co-ordinate and even integrate these two processes.

This report focuses on scenario-based LT-LEDS and explores the level of alignment between government institutions in the process of developing LTES and scenario-based LT-LEDS, to assess possible interventions to improve the development, communication, and implementation potential of these scenarios.

Highlights of the report include the following:

- Of the LTES documents collected, two-thirds are published by the energy ministries or their equivalents, while 18% are published by dedicated energy planning institutions or technical agencies. Half of the scenario-based LT-LEDS are published by the ministries of environment.
- Integrated ministries (ministries that cover an interdisciplinary portfolio, for example, energy and climate, or economics and energy) account for 28% of submissions of scenario-based LT-LEDS and 5% of LTES in the sample. Approximately 10% of both LTES and scenario-based LT-LEDS are published as joint publications of multiple ministries.
- All LTES and scenario-based LT-LEDS collected for this analysis used modelling tools to formulate scenarios. On average, LTES include five scenarios and LT-LEDS include four scenarios in their analysis.
- Stakeholder consultations are a common practice in the development of both LTES and scenario-based LT-LEDS. Of the scenarios collected, 67% of the LTES and 94% of the scenario-based LT-LEDS referred to a stakeholder consultation process, primarily with subject experts.
- Scenario-based LT-LEDS tend to cover emerging technologies better than LTES, reflecting their longer planning time horizon and target-based backcasting approach.
- Both types of scenarios generally represent the energy supply side better than energy end-use. Notably, electricity network infrastructure is better presented in LTES, while energy efficiency is better presented in LT-LEDS.
- Some socio-economic factors, such as jobs, public health and welfare, are more comprehensively represented in LT-LEDS than in LTES, highlighting their economy-wide and development focus.
- Land use, land-use change, and forestry (LULUCF) is included in one-third of LTES and 95% of LT-LEDS.
- Global critical mineral availability is assessed in only 8% of LTES and 14% of LT-LEDS.

Basing energy planning on scenarios is a proven way to lead to robust and trusted plans. Scenario-based energy planning requires a robust assessment methodology, which entails increased stakeholder engagement, as well as traceability and accountability of scenario outputs. Building on the earlier findings of the LTES Network (IRENA, 2020) this report concludes with certain observations that may be useful to government practitioners developing scenarios in both LTES and scenario-based LT-LEDS, as can be seen in the figure below.

Figure 1 **Guidelines for developing effective LTES and scenario-based LT-LEDS**

Co-ordinate	Ensuring **institutional co-ordination within the government sector** when developing long-term scenarios with energy, climate and other institutions can help **leverage diverse sectoral expertise** for a broader scope, ensure high-quality data and quality assurance, and avoid duplication of work. **Scenarios contribute to this**.
Engage	Engaging a **broad range of stakeholders** and dedicating special resources can ensure **participatory and inclusive inputs** into the planning document and can result in more robust data, more buy-in from different stakeholders, and effective communication of scenarios with different actors.
Develop	Developing scenarios that go beyond traditional energy scenarios by including **socio-economic impacts, future technologies and robust power transmission and distribution** can capture the cost of the transition, highlight its positive human impacts and address immediate social and economic concerns.
Communicate	Producing **strong communication and outreach strategies** for LTES and LT-LEDS allows them to act as powerful drivers of technology transfer and a signal for technology developers, investments, and cross-border collaboration.
Implement	Leveraging the ambitions and visibility of LT-LEDS as a **driver for policy making, legislation and regulation** can ensure their ambitions are **enshrined in law** and can positively affect implementation by both government and non-government sectors.

INTRODUCTION

BACKGROUND TO THIS STUDY

Effective climate action requires all countries to enact transformative changes in their energy systems, with far-reaching implications across industry, transport, buildings, agriculture and land use, and other sectors. Future energy systems could look entirely different from those of the present, with major use of renewable energy sources, flexible and decentralised grids, sustainable transport and more energy efficiency. Electrification, decentralisation and digitalisation can support new business models and changes in consumer behaviour, radically transforming whole systems.

Long-term energy planning is a process whereby national or regional targets, policies and investment strategies are derived from quantitative analysis of the development prospects of the energy sector. It represents an opportunity for countries to envision these changes in relation to the future of their economy and climate targets. IRENA, through its Long-term Scenarios for the Clean Energy Transition Network (LTES Network), promotes the use of long-term energy scenarios (LTES) for effective energy planning, particularly in navigating policies through the complexities of climate change, energy security, access, reliability, socio-economic development and economy-wide transitions to new, disruptive technology and business models.

LTES Network members are represented by scenario practitioners in national governments. In the network, members share their experiences of how they are changing and improving their development and use of LTES in planning for the clean energy transition. In recent years, LTES Network members have increasingly experienced the need to integrate climate objectives into the energy planning process. While climate and energy policy making are traditionally driven by different government ministries, the LTES Network has collected many examples of how these processes are increasingly better co-ordinated and integrated.

The 2015 Paris Agreement marked a turning point in climate policy. Governments agreed to communicate actions they would take to keep the increase in average global temperatures below 2°C in Nationally Determined Contributions (NDCs) in a five-year cycle of increasingly ambitious climate action. The United Nations Framework Convention on Climate Change (UNFCCC) launched a parallel process encouraging countries to submit long-term low [greenhouse gas] emission development strategies (LT-LEDS)[1] to identify strategies for a transition to a low greenhouse gas (GHG) economy. Parties were invited to communicate their LT-LEDS to the UNFCCC by 2020. The strategies explore the mid-century goal for the just transition to global net-zero emissions. As countries continue to submit their LT-LEDS, the UNFCCC – a partner of the LTES Network – has synthesised the submitted LT-LEDS, as mandated by the Glasgow Climate Pact (UNFCCC, 2022).

This report presents the results of an exercise to stocktake official national LTES, which IRENA conducted in parallel and in co-ordination with the UNFCCC's stocktaking of LT-LEDS, and aims to complement the UNFCCC's recently published synthesis report on LT-LEDS (UNFCCC, 2022). The report analyses the alignments and misalignments between energy policy goals and climate goals as observed through a comparison of the LTES and scenario-based LT-LEDS. It also suggests ways to increase coherence and synergies between energy and climate policies.

This stocktaking exercise focuses on the institutional set-up that governs the development and use of LTES, and their coverage of energy transition elements. It is also a part of the comprehensive collection of data from LTES published in IRENA's National Energy Transition Planning dashboard[1] on the IRENA website.

The following sections provide more detail on the focus of this report, and the background of both LTES and LT-LEDS.

[1] *www.irena.org/Energy-Transition/Planning/Long-term-energy-planning-support*

LTES

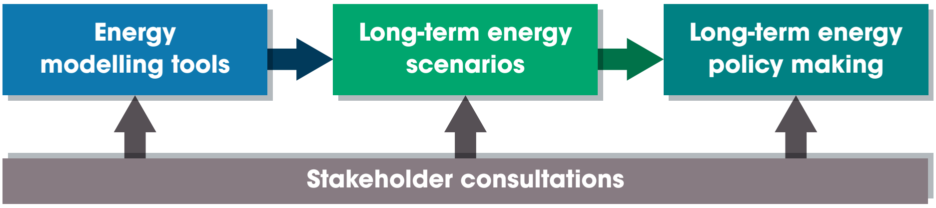
LTES explore socio-technical pathways for the energy sector (or a subset of the energy sector, such as the power sector) over 15 years or longer, to help inform productive national and international policy debates, allowing governments to develop well-informed long-term visions and associated energy policies. LTES help governments prepare for the long-term interventions required to meet policy goals, and assist in identifying the short-term challenges to – and opportunities for – achieving the desired energy future. LTES are also used to inform recommendations on where to direct investment, to ensure that projected demand can be met at the lowest cost. Figure 2 shows the mental model of this process as presented by the LTES Network.

Many LTES are published in energy planning documents prepared by the designated entity responsible for energy policy making. These documents are typically updated at regular intervals to reflect evolving demand and supply projections and to ensure security of supply in the energy system, so that energy planning can be adjusted accordingly. Certain LTES explicitly mention a framework for regular updates. For example, Chile's *Planificación Energética de Largo Plazo* is updated every five years (Ministry of Energy, Chile, 2021), while the Dominican Republic updates its *Plan Energético Nacional* every 15 years (Ministry of Energy and Mines, Dominican Republic, 2022). Other countries have comparatively less formal arrangements: the Marshall Islands and the Philippines both update their LTES on an as-needed basis (DOE, 2018; National Energy Office, Marshall Islands, 2018). The process of developing long-term energy planning can be written into law alongside climate and/or energy targets, or be a less formal process with ad hoc institutional arrangements. Examples of countries that have legislated their climate targets can be found in Box 1 below. Some degree of stakeholder consultation is typically part of these processes. How these processes are governed differs significantly across jurisdictions.

Box 1 Legislation of targets to enhance implementation

The legislation of emission targets at the national level can be useful in aligning objectives across different planning documents. Chile's General Law of Electrical Services defines environmental policies that have an impact on both mitigation and adaptation, such as the Climate Change Framework Law, the Climate Change Framework Law and the commitment to Carbon Neutrality. It is also considered to be a main input to the National Energy Policy. In Uruguay, the National Policy on Climate Change is an instrument that provides the long-term strategic framework to guide the transformations that the country has been undergoing to meet the challenges of climate change, including energy policy (IRENA, 2022). Finally, Germany legislated its emission reduction targets by 2030 and 2040, aiming for net-zero emissions by 2045, and added extra funding to their climate action programme (German Federal Ministry of Finance, 2021). This provides clarity on concrete climate targets and indicates the political will to realise them, serving as an anchor point for other actors in the energy transition and speeding up the transition.

Figure 2 **How scenarios are developed and used: A mental model for the LTES Network**



Despite these differences, many countries and institutions are expanding the scope of their LTES to include features, concepts and narratives relevant to climate targets. Often governments' LTES have tended to be conservative in their estimates of what can be achieved in terms of renewable energy, electrification and energy efficiency, and underplay the role of disruptive technology and business models like decentralisation, digitalisation and electrification (IRENA, 2020a). However, countries have begun elaborating strategies to inform the operationalisation of net-zero pathways as required by the Paris Agreement. Thus, LTES and their role as official energy policy documents have become increasingly ambitious in their climate aspirations and the extent and speed of the clean energy transition.

LT-LEDS

In accordance with Article 4.19 of the Paris Agreement, all Parties should strive to formulate and communicate LT-LEDS, mindful of Article 2: "taking into account their common but differentiated responsibilities and respective capabilities, in light of their different national circumstances" (UNFCCC, 2022). Most LT-LEDS consider multiple technological and socio-economic pathways and include emission targets with different levels of ambition. At the same time, over 70 countries have committed to achieving net-zero emissions by around mid-century (Net Zero Tracker, 2022); 28 countries with both LT-LEDS and net-zero commitments have used LT-LEDS to explore different strategies for reaching net-zero emissions. The trend of incorporating net-zero targets into LT-LEDS is relatively recent, but may gain momentum as more countries raise the ambition of their climate goals.

LT-LEDS are a national, high-level policy instrument that build upon, and influence, existing national strategies and processes. They can be regarded as a tool with which to explore the challenges and opportunities associated with the structural transformations needed to reach carbon neutrality, confront the consequences of alternative pathways towards this end goal and inform the differentiated consequences of various actors (IDDRI, 2021). Article 26 of the Sharm el-Sheikh Implementation Plan urges countries to communicate their progress towards achieving net-zero emissions by or around mid-century (UNFCCC Secretariat, 2022).

At a national level, LT-LEDS align climate action with national economic development and help to identify and prioritise mitigation actions by providing a comprehensive analysis of mitigation costs, potential synergies and the risks associated with trade-offs. At the international level, LT-LEDS support the global goal of GHG emissions reduction and may help attract climate finance (Levin *et al.*, 2018). LT-LEDS should ideally be holistic in nature, in the sense that they should incorporate all key sectors of the economy along with sectoral pathways and strategies to achieve different milestones (Climate Analytics, 2022).

Energy and emissions modelling and scenario analysis can constitute an important part of LT-LEDS, allowing them to quantitatively address national circumstances and aspirations, key focus areas and challenges facing sectoral transformation. However, analysis suggests that climate policy documents may lack coherence with energy policies. The IRENA report *NDCs and renewable energy targets in 2021* analysed renewable energy targets for the power sector in both NDCs and national energy plans and policies. The analysis finds that 82 countries had set renewable targets in both national policies and NDCs as of October 2022, while 67 had set them only in national plans and 26 only in NDCs; 21 countries have not made any specific commitments (IRENA, 2022b).

COMPARING LTES AND LT-LEDS

While the development of LT-LEDS is a relatively recent addition to the national planning process, LTES have been widely developed for decades. As mentioned, LTES are usually developed by a government authority responsible for energy policy making, while LT-LEDS are developed by a government authority responsible for climate or development policy. There are varying levels of co-ordination between these two processes, ranging from the processes being totally unco-ordinated to the processes being unified.

LT-LEDS address the decarbonisation of the whole economy. As such, the sectoral scope is expected to be broader than LTES, which typically address energy production and use. LT-LEDS typically cover a time horizon of 2050 or beyond, while LTES are typically developed with a 15–30-year time horizon, as their purpose tends to be ensuring security of supply in a changing energy system; they have a clear purpose of informing short- and medium-term policy and investment decisions, rather than developing roadmaps towards net-zero emissions. LTES increasingly address environmental implications, and alignment with net-zero targets is also increasingly included in their scope. Given their relevance to the energy sector, LTES tend to focus on CO_2 emissions rather than all GHG emissions.

Table 1 **Key characteristics of LTES and LT-LEDS**

	LTES	LT-LEDS
Time horizon	15-30 years	At least until 2050
Scope	Energy or power sector	Whole economy
Publishing institutions	Typically energy ministries or planning institutions	Typically environment or climate ministries
Purpose	Ensuring a secure, affordable and sustainable energy supply	Reaching net-zero emissions

STOCKTAKING METHODOLOGY

The stocktaking exercise in this report covers scenario-based LT-LEDS and LTES from countries with official submissions to the UNFCCC, or from countries that are members of the IRENA LTES Network. The countries within this scope were sent a survey on the institutional characteristics of their planning documents, such as the institutions responsible for publication, publication year and planning time horizon, as well as scenario metadata, including the number and key features of the scenarios. The survey was collected through LTES Network focal points as well as IRENA's national focal points in respective countries. Where this was not possible, robust desk-based research was performed to obtain the information required and sent to the respective country for validation. The survey can be found in the appendix.[2]

For LTES,[3] only documents that meet both the following criteria were included in the analysis:

- Developed within the last five years.[4]
- With a planning horizon longer than 15 years.

Of 53 LT-LEDS communicated to the UNFCCC as of October 2022 (submitted by 52 countries and the European Union), 36 are based on scenarios, and those are included in this analysis. Hereafter, the LT-LEDS analysed in this report are referred to as scenario-based LT-LEDS. All of these scenario-based LT-LEDS have a planning horizon of 2050 or longer. For LTES, 24 documents from 21 different countries were identified. Of these 24 LTES, 14 have a planning horizon until 2050, with the remaining 10 having a planning horizon until at least 2035. The average horizon year of the LTES included in this report is 2045. The geographical spread of the documents included in this report can be seen in Table 2 below.

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[2] In some countries a government body may produce a dedicated "net-zero" emissions scenario study, often as an extension of the LTES process. Such a study may or may not be used as an official LT-LEDS submission. Where available, these documents are also included in the scope of this report as LTES.

[3] For the purpose of this study, official LTES are identified as "produced or commissioned by an official government body as part of the energy planning process and in the country's long-term energy planning documents, which are typically updated at a regular interval."

[4] This report focuses on relatively recent LTES documents to ensure that all the documents compared were developed at a time when countries already had a clear understanding of their NDCs and future climate targets after the Paris Agreement.

Table 2 **Geographical spread of planning documents included in this report**

Continent of origin of planning document	LTES	Scenario-based LT-LEDS
Africa	2	2
Asia and the Pacific	3	7
Europe	8	19
Latin America	9	6
North America	2	2

Some countries submitted a survey for planning documents that did not fit the scope of this report. For some background on these documents that had to be excluded from the analysis, see Box 2. Many of these are featured in the LTES Energy Planning Dashboard.[5]

Box 2 **Additional surveys received but excluded from the analysis**

In addition to the surveys analysed in this report, IRENA received completed surveys outside the scope of this report. Most of these documents were excluded because of the length of their planning horizon or their more limited scope. LTES cover a time horizon of at least 15 years past their publication date. Most planning documents excluded from analysis in this report are National Energy and Climate Plans (NECPs), published by member states of the European Union, which run until 2030 and therefore have a planning horizon of less than 15 years. Two exceptions to this are the Integrated NECPs from Germany and Italy, which voluntarily have a time horizon and modelled trajectories to 2040, meaning they fit the scope of this report.

As discussed above, this report is based on a total of 24 LTES documents and 36 scenario-based LT-LEDS. For the majority of countries only an LTES or an scenario-based LT-LEDS was identified, not both. For 12 countries both LTES documents and scenario-based LT-LEDS were identified. Three countries (Chile, Germany and Italy) have multiple LTES without one superseding the other. In the case of Chile, its two LTES have different purposes: the first planning document, *Planificación Energética de Largo Plazo*, develops scenarios for national energy demand and supply over

[5] *www.irena.org/Energy-Transition/Planning/Long-term-energy-planning-support*

at least 30 years for inclusion in the national network planning process (Ministry of Energy, Chile, 2021), while the second, *Carbono Neutralidad en el Sector Energía*, maps out pathways towards carbon neutrality (Ministry of Energy, Chile, 2020). Germany and Italy both have their own national LTES, and as EU members they also submit NECPs, which are national strategies required to cover a time horizon until at least 2030. Germany and Italy have extended the time horizon of their NECP scenarios until 2040 (Federal Ministry of Economic Affairs and Climate Action, Germany, 2020; Ministry of Ecological Transition, Italy, 2020), allowing their inclusion in this analysis.

Once the institutional survey was completed, it was followed by a technical survey in which countries were asked to assess their scenarios' coverage of clean energy transition elements. The survey comprised 62 elements of the future energy system, from production to end use, as well as socio-economic factors, against which the LTES and scenario-based LT-LEDS were evaluated. More detail on these 62 elements can be found in Chapter 2. The coverage of the individual elements was categorised under one of the following:

- "Quantitative", indicating that the component was explicitly included in the scenario, and was represented in a quantitative manner.
- "Qualitative", indicating that the component was represented in the scenario in a qualitative manner as a part of the overall narrative, but not as its own specific option with quantitative parameters.
- "Not included".

STRUCTURE OF THE REPORT

This report is divided into two main parts. Chapter 1 explores the results of the institutional survey for the LTES and scenario-based LT-LEDS documents included in this analysis. It discusses key attributes of both types of planning document, such as publishing institution, modelling tools used and whether a stakeholder consultation was held as part of the document's development process. Chapter 2 discusses the results of the technical survey of the same set of LTES and scenario-based LT-LEDS, outlining the coverage of the scenarios. The report concludes with good practices and suggestions on how to improve the development of planning documents.

CHAPTER 1

PROCESSES AND GOVERNANCE BEHIND LTES AND SCENARIO-BASED LT-LEDS

The clean energy transition is a complex process involving a range of stakeholders that spans public administration, industry, businesses, local communities and the international sphere. To achieve the transition, a country's governance structures should engender broad participation and strong co-ordination. Past dialogue with countries through IRENA's LTES Network has consistently highlighted the importance of a highly co-ordinated and strong governance structure – one that is also highly participatory and inclusive with a multi-institutional approach. Different countries have varying political, social and economic contexts that necessitate and allow for different governance frameworks. This creates a highly diverse set of practices that can be adopted and integrated in other interested countries. This section aims to take stock of the institutional set-up behind the development and publication of scenario-based long-term planning documents, to understand the current global landscape and highlight relevant good practices shared through the activities of the LTES Network.

KEY ATTRIBUTES

Tables 3 and 4 summarise the LTES and scenario-based LT-LEDS collected for this stocktaking exercise, and their key attributes.

Table 3 **Key attributes of the LTES collected for this analysis**

Country name	Document name	Year of net-zero emission target, if applicable	Planning time horizon
Belgium	Scenarios for a Climate Neutral Belgium by 2050	2050	2050
Brazil	Plano Nacional Energia PNE 2050		2050
Canada	Canada's Energy Future 2021	2050	2050
Chile	Planificacion Energética de Largo Plazo 2023-2027	2050	2050
Chile	Carbono Neutralidad en el Sector Energía	2050	2050
Colombia	Plan Energético Nacional 2020-2050		2050
Costa Rica	Plan de Expansión de la Generación Eléctrica 2020-2035		2035
Denmark	Denmark's Climate Status and Outlook		2035
Dominican Republic	Plan Energético Nacional 2022-2036 (PEN)		2036
El Salvador	Estudio Prospectiva Energética 2020-2035		2035
Finland	Carbon Neutral Finland 2035	2035	2050
Germany	Projektionsbericht 2021		2040
Germany	Integrated National Energy and Climate Plan		2040
Guatemala	Plan de Expansión Indicativo del Sistema de Generación 2020-2050		2050
Indonesia	Indonesia Energy Outlook 2019		2050

Italy	Strategia italiana di lungo termine sulla riduzione delle emissioni dei gas a effetto serra	2050	2050
Italy	Integrated National Energy and Climate Plan		2040
Kenya	Updated Least Cost Power Development Plan		2041
Marshall Islands	RMI Electricity Roadmap	2050	2050
Mexico	Estrategia de Transicion para Promover el Uso de Tecnologías y Combustibles Más Limpios		2050
North Macedonia	The Strategy for Energy Development of the Republic of North Macedonia until 2040		2040
Philippines	Philippine Energy Plan: Towards a Sustainable and Clean Energy Future		2040
South Africa	Integrated Energy Plan 2016		2050
United States	EIA Annual Energy Outlook 2022		2050

Table 4 **Key attributes of the scenario-based LT-LEDS collected for this analysis**

Country name	Document name	Year of net-zero emission target, if applicable	Planning time horizon
Andorra	Long-Term Strategy on Energy and Climate Change	2050	2050
Australia	Australia's Long Term Emissions Reduction Plan	2050	2050
Austria	Long-term Strategy 2050 - Austria	2050	2050
Cambodia	Long-term Strategy for Carbon Neutrality (LTS4CN) for Cambodia	2050	2050
Canada	Canada's Long-Term Strategy	2050	2050
Chile	Estrátegia Climatica de Largo Plazo de Chile	2050	2050
Colombia	E2050 Colombia. Estrategia Climática de Largo Plazo de Colombia E2050 para Cumplir con el Acuerdo de París	2050	2050
Costa Rica	Plan Nacional de Descarbonización 2018-2050	2050	2050
Czech Republic	Climate Protection Policy of the Czech Republic		2050
Fiji	Fiji's Low Emission Development Strategy 2018-2050	2050	2050
Finland	Finland's Long-Term Low Greenhouse Gas Emission Development Strategy	2035	2050
France	National Low Carbon Strategy	2050	2050
The Gambia	The Gambia's Long-Term Climate-Neutral Development Strategy 2050	2050	2050
Guatemala	Estrategia Nacional de Desarrollo con Bajas Emisiones de Gases de Efector Invernadero		2050
Hungary	National Clean Development Strategy 2020-2050	2050	2050
Iceland	On the Path to Climate Neutrality: Iceland's Long-Term Low Emission Development Strategy	2040	2050

Indonesia	Indonesia. Long-Term Strategy for Low Carbon and Climate Resilience 2050		2050
Latvia	Latvia's Strategy to Achieve Climate Neutrality by 2050	2050	2050
Malta	Malta Low Carbon Development Strategy	2050	2050
Marshall Islands	Tile Til Eo – 2050 Climate Strategy "Lighting the way"	2050	2050
Mexico	Mexico's Climate Change Mid-Century Strategy		2056
Nepal	Nepal's Long-term Strategy For Net-zero Emissions	2045	2050
North Macedonia	Long-term strategy on climate action and action plan		2050
Portugal	Roadmap for Carbon Neutrality 2050 (RNC2050)	2050	2050
Russian Federation	Strategy of socio-economic development of the Russian Federation with low greenhouse gas emissions until 2050		2050
Slovakia	Low-Carbon Development Strategy of the Slovak Republic until 2030 with a View to 2050		2050
Slovenia	Resolution on Slovenia's Long-Term Climate Strategy until 2050	2050	2050
South Africa	South Africa's Low-Emission Development Strategy 2050		2050
Spain	Spanish Long Term Low GHG Emission Development Strategy 2050	2050	2050
Sweden	Sweden's long-term strategy for reducing greenhouse gas emissions	2045	2050
Switzerland	Switzerland's Long-Term Climate Strategy	2050	2050
Thailand	Mid-century, Long-term Low Greenhouse Gas Emission Development Strategy	2065	2065
United Kingdom	UK Net Zero Strategy: Build Back Greener	2050	2050
Ukraine	Ukraine 2050 Low Emission Development		2050
Uruguay	Estrategia Climática de Largo Plazo de para un Desarollo Bajo en Emisiones de Gases de Efecto Invernadero y Resiliente Al Clima	2050	2050
United States	The Long-Term Strategy of the United States Pathways to Net-Zero Greenhouse Gas Emissions by 2050	2050	2050

As can be seen from Table 2, 7 of the 24 LTES include some form of net-zero emissions target (a net-zero CO_2 target or a net-zero GHG target), and 27 of the 36 scenario-based LT-LEDS also include such targets.

PUBLISHING INSTITUTIONS

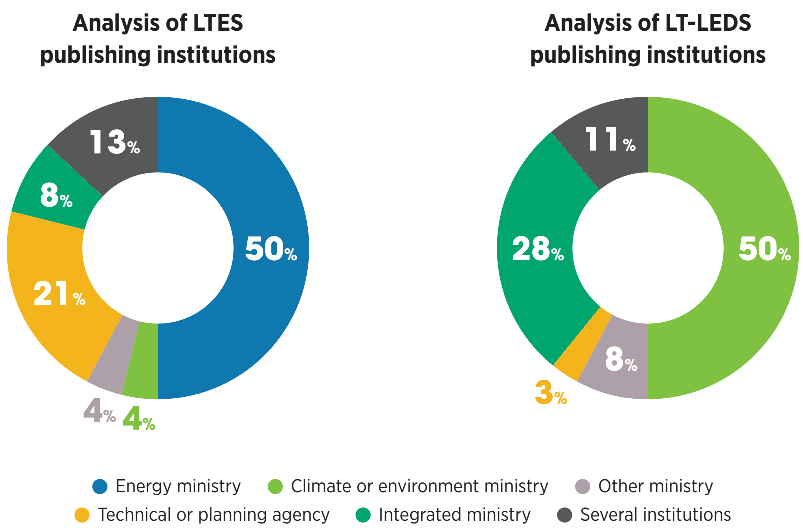
Broadly, **LTES documents** are published by government ministries responsible for energy[6] or by specialised energy planning institutions, or they are published as joint publications by two ministries (usually energy, climate and/or environment, or one "integrated ministry" that covers an interdisciplinary portfolio). In this report, an "integrated ministry" refers to a ministry responsible for several interdisciplinary portfolios, which can include climate, the environment, energy, economic development and more. An example of such a ministry is Finland's Ministry of Economic Affairs and Employment, which is also responsible for national energy policy. Of the countries surveyed, half published their LTES documents through their equivalent of an energy ministry, while the rest were divided between planning institutions, environment ministries and integrated ministries. Three of the surveyed documents (13%) included multiple ministries as the main publishers of the LTES planning document.

Half of the **scenario-based LT-LEDS** surveyed were published by the country's equivalent of an environment ministry, while 28% were published by integrated ministries, and 11% were jointly published by several ministries. A further 8% of scenario-based LT-LEDS were published by other ministries (such as the Ministry of the Economy in Slovakia).

As can be seen in Figure 3 below, integrated ministries publish scenario-based LT-LEDS more often than LTES. These integrated ministries with their broad portfolios can be well-suited to the development of scenario-based LT-LEDS, which map out low-carbon development strategies for the whole economy and typically adopt big-picture approaches to climate goals.

[6] *A ministry was determined as being responsible for energy policy if it has "energy" in its formal name. Similar categorisations were made for ministries responsible for climate and environmental policy.*

Figure 3 **Publishing institutions for LTES and scenario-based LT-LEDS included in this report**



In order to investigate the possible correlation between publishing institutions and the scope of the scenarios, the comprehensiveness of the scenario coverage was assessed based on the responses to the technical survey, where countries indicated whether they covered the 62 elements of the energy transition in a quantitative or qualitative manner, or not at all. Elements that were included quantitatively are assigned a 3, qualitatively a 2, and elements that were not included in the scenarios are given a 1. The average of the variables in a particular selection of elements thus indicates the comprehensiveness: the higher the average, the higher the level of detail on the elements and inclusion in the scenarios. As the table below shows, planning documents published by an integrated ministry or multiple ministries tend to contain a higher level of comprehensiveness than planning documents published by a single ministry, especially in the case of the LTES included in this report.

Table 5 Inclusion of energy transition elements in the scenarios covered in this report

Published by	LTES score	Scenario-based LT-LEDS score
Single ministries	1.75	1.72
Multiple ministries	2.05	1.83
Integrated ministries	2.44	2.10
All documents	**1.84**	**1.84**

Boxes 3 and 4 highlight examples of co-ordination across government institutions, and with non-government sectors in academia and the private sector, for the development of scenarios.

Box 3 Examples of co-ordination across government institutions for the development of scenarios

Determining which decisions governments must take in the next two, five and ten years to reach energy sector and climate goals requires high-level institutional co-ordination. Institutions responsible for LTES and scenario-based LT-LEDS can co-operate to identify synergies between energy planning processes and climate policy. In the United Kingdom energy planning processes are co-ordinated with climate action at a high level. Every ministry is required to take national emission reduction objectives (including the UK net-zero target and carbon budgets) into account when making decisions. Climate action is considered relevant not only to energy policy, but also to growth and economic policy (IRENA, 2020b). The UK has also published a ten-point plan for a green industrial revolution, which prioritises offshore wind and other renewable sources of energy.

In the IRENA webinar series on LTES in Latin America and the Caribbean, held in 2021, a number of governments highlighted that they are adopting formalised interministerial and intraministerial co-operation processes to align LTES with climate policies (IRENA, 2022). In Chile, the Electricity Services Act requires co-ordination between the National Energy Policy, the Framework Law on Climate Change and different national sectoral policies, strategies and commitments. All these policy documents serve as inputs for Chile's long-term energy planning, which is updated annually (IRENA, 2022a). In Costa Rica the Climate Change Directorate of the Ministry of Environment and Energy oversees long-term energy scenario planning while accounting for climate mitigation imperatives.

Another example of alignment between different policy processes is horizontal co-operation, for example through interministerial bodies, that clearly allocates responsibilities to relevant stakeholders in the country as part of the process of developing their LTES. The Ministry of Energy of Honduras has created an internal Climate Change Committee that participates in the national Interministerial Climate Change Committee that is responsible for developing the country's NDC and long-term strategy (IRENA, 2022). Additionally, Honduras' National Energy Policy sets short-, medium- and long-term targets aligned with the NDC, Sustainable Development Goals and decarbonisation targets to be achieved in 2050. Uruguay has also created a strong governance structure, with the participation of the Ministry of Industry, Energy and Mines in the inter-institutional group for the Climate Change Response System. Cambodia's National Council for Sustainable Development, housed within the Ministry of Environment, co-operates with an interministerial team that has representatives from other ministries. Both the National Council for Sustainable Development and the interministerial team participated in the elaboration of Cambodia's scenario-based LT-LEDS. El Salvador's Consejo Nacional de Energía, which is chaired by the Ministry of the Economy, includes members from the Ministry of Environment and Natural Resources, the Treasury, and the Ministry of Public Works and Consumer Protection. All members collaborated on the development of El Salvador's LTES.

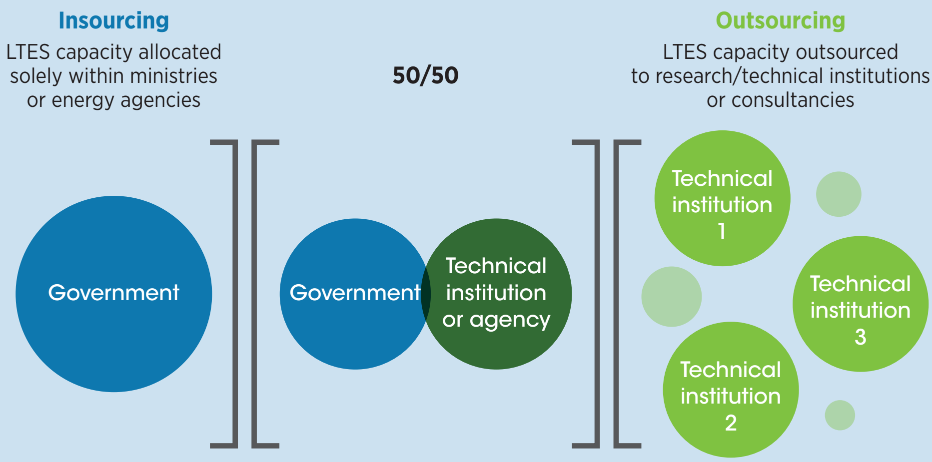
Institutions should also plan the monitoring of LTES, scenario-based LT-LEDS and their effects in order to identify trade-offs and tensions with other policies and priorities. Canada has developed a Federal Energy Information Framework, which relies on co-operation between different government agencies including Statistics Canada, Natural Resources Canada, the National Energy Board and the EEC (IRENA, 2020b).

These examples show that setting out clear responsibilities at the ministerial and subnational levels, as well as opening channels of co-operation between ministries and institutions responsible for different sectors, can contribute to greater efficiency and policy coherence.

Box 4 Government collaboration with academia and the private sector

While ministries remain ultimately responsible for approving and publishing LTES documents and scenario-based LT-LEDS, consultancies, civil society organisations and academic institutions are sometimes invited to execute analytical work underlying the documents. Figure 4 indicates possible task divisions between government and external institutions when it comes to the building of scenarios.

Figure 4 Allocation of scenario building capacity from the government's perspective



Source: IRENA (2020a).

Possible advantages of involving external institutions are greater scenario diversity and possibly higher-quality scenarios, as governments can rely on external experts as well as their own (IRENA, 2020a). One example of governments involving experts on different topics is Austria. For the development of its scenario-based LT-LEDS, Austria collaborated with numerous organisations to develop its Long-Term Strategy 2050: the Center of Economic Scenario Analysis and Research and the Austrian Institute of Economic Research, the Institute for Internal Combustion Engines and Thermodynamics at the Graz University of Technology, the Institute for Transport Studies at the Vienna University of Technology and the Energy Economics Group of the Vienna University of Technology (Federal Ministry for Climate Protection, Austria, 2020).

A further example is Cambodia; the country's National Council for Sustainable Development partnered with multiple international organisations and think tanks to develop its scenario-based LT-LEDS, including the Cambodia Climate Change Alliance programme (funded by the European Union, Sweden and the United Nations Development Programme), the World Bank, the Food and Agriculture Organization of the United Nations, the Agence Française du Développement and the Global Green Growth Institute (Ministry of Environment, Cambodia, 2021). The Gambia collaborated with consultants from Pakau Consultancy to support its modelling (Ministry of Environment, The Gambia, 2022).

STAKEHOLDER CONSULTATION

As the energy transition presents more complex challenges and a more diverse range of affected stakeholders, inclusive stakeholder consultation has been increasingly highlighted within the activities of the LTES Network as a key component in national energy scenario development. It can serve as a method of collecting data and inputs, understanding the concerns of different parties, creating a more participatory process and a feeling of ownership among stakeholders, and communicating scenario outcomes.

Of the LTES documents, 67% involve stakeholder consultation at some point of the modelling, analysis and publishing process. When involving stakeholders, LTES documents mainly relied on consultations with experts from industry, academia and various government and non-governmental organisations, with others involving open consultations with the public.

Of the scenario-based LT-LEDS documents, 34 out of 36, or 94%, involve stakeholder consultation. Similar to the LTES that held stakeholder consultations, scenario-based LT-LEDS also mainly involved consultations with other ministries and technical institutions, the private sector and academia. Out of the 34, 11 scenario-based LT-LEDS involved closed or invitation-only consultation with experts. It should be noted that not all documents specified the type of stakeholder consultation they held.

Both LTES and scenario-based LT-LEDS included examples of stakeholder consultations with a clear focus on only expert consultations. Other LTES and scenario-based LT-LEDS included consultations with the broader public, trade unions, industry representatives and historically marginalised or Indigenous communities, among others.

Previous discussions held in the context of the LTES Network highlighted the need for the processes used to develop scenarios within LTES and scenario-based LT-LEDS to be participatory and inclusive to ensure the robustness and diversity of input data. They should embrace all relevant stakeholders including the private sector, academia, civil society organisations and actors from historically marginalised communities, and be suitable as a method to communicate the results of the scenarios. The resulting planning documents and scenario-based LT-LEDS can thus reflect the viewpoints of different stakeholders, including convergences and potential disagreements. Further recommendations gathered by IRENA are highlighted in Boxes 5 and 6.

Box 5 **Example of good practice – stakeholder consultation in energy planning processes**

Argentina's dialogue "Towards a Shared Vision of Argentina's Energy Transition to 2050" is an example of an inclusive consultation process to define feasible scenarios in a national context and allow for easier communication of scenario insights. The dialogue was convened by the Secretariat of Energy and conducted by the Executive Committee of the Argentine Energy Scenarios Platform. The process was based on a back-casting approach (from the future to the present), in which it was proposed to agree on the desired situation of the Argentine energy system by 2050 and on several other transition objectives (IRENA, 2022).

Box 6 **Recommendations from the scientific community on improving participatory processes**

In 2022, IRENA organised an event at the International Energy Workshop conference to gather experience on participatory processes and stakeholder consultation from the scientific community. The key findings from this event are intended to support government planners in improving their communication practices around energy transition scenarios and help frame future LTES activities with governments.

Giving serious consideration to alternative and potentially conflicting viewpoints can increase the robustness of the stakeholder consultation process. An additional step is to assess the extent to which stakeholder inputs contributed to modelling or the development of policy strategies, either during the development of the scenarios or afterwards. Comprehensive consultation processes can increase the sense of ownership of energy planning on the part of stakeholders.

The scientific community highlighted benefits of strong participatory processes for narrowing down the scope of the model and number of conceivable scenarios, building trust and buy-in from stakeholders and leveraging scenario development for the communication of scenario insights. Specific recommendations included providing dedicated resources and capacity for the process of stakeholder consultation (such as setting up dedicated units to organise the process), developing interactive participatory meetings with visualisation and gamification elements, organising participation at various geographical levels (local and regional) and comparing the results of different processes to encourage institutional learning and allow for continuous improvement of stakeholder outreach.

SCENARIO SCOPES AND TOOLS

Modelling tools are often at the heart of building quantitative scenarios. They are based on models that vary in complexity from simple calculator models to complex whole energy system optimisation models. Each can have its place within the energy planning framework.

The number of scenarios used in the LTES and LT-LEDS publications varies, ranging from a single scenario (Andorra's scenario-based LT-LEDS, and the LTES of Denmark, Germany and Italy) to 40 (in El Salvador's LTES) (DEA, 2020; Environment Agency of Germany, 2021; Ministry of Ecological Transition, Italy, 2020; National Council of Energy, El Salvador, 2020). On average, LTES documents included five scenarios, and scenario-based LT-LEDS documents contained four.

While scenarios do not strictly have to be modelled, all the LTES and scenario-based LT-LEDS that were assessed in this report did use modelling. Over 70% of LTES documents surveyed used tools to model the entire energy sector, such as TIMES, MESSAGE or LEAP. Exactly half of scenario-based LT-LEDS and just over half (55%) of the LTES included in this report relied on macroeconomic models specific to their technical and economic contexts. Costa Rica, for example, used OSeMOSYS-Costa Rica for their LT-LEDS (Costa Rica Gobierno de Bicentenario, 2019). The Czech Republic used a version of ALADDIN-CLIMATE in their LT-LEDS specifically adapted to their country's energy system, ALADDIN-CLIMATE/CZ (Ministry of Environment, Czech Republic, 2018). Other countries have also included sector-specific modelling tools coupled with a broader energy model. Switzerland, for example, combined INFRAS AG for the transport sector with tools modelling the entire energy sector (Federal Office of Energy, Switzerland, 2021). A comprehensive list of modelling tools used by the countries included in this analysis can be found on the LTES Network's Energy Planning Dashboard.[7]

The surveys also gauged whether the scope of the scenario development exercises explicitly assessed demand, the international context (*i.e.* trade), the whole energy system, and power system capacity expansion in the scenario analysis, including at the narrative level. LTES generally all assessed projected energy demand and power systems alongside the whole energy system. The exceptions are three LTES from the Marshall Islands, Kenya and Costa Rica, which are purely power system-focused (Costa Rican Institute of Electricity, 2021; Ministry of Energy, Kenya, 2022; National Energy Office, Marshall Islands, 2018). Of the LTES documents, 75% integrated inputs external to their borders, likely due to the modelling of regional electricity interconnections.

Scenario-based LT-LEDS tended to feature more integrated frameworks that contained modules such as energy system models (similar to those used in LTES), emission inventories and sector-specific models (such as transport and hydrogen) due to their general economy-wide scope. Fewer scenario-based LT-LEDS assessed power system expansion and its components, but all assessed the energy system as a whole, and all but one performed a projected energy demand assessment.

[7] *www.irena.org/Energy-Transition/Planning/Long-term-energy-planning-support*

The modelling tools most commonly used by both LTES and scenario-based LT-LEDS included in this report are the LEAP model and (adaptations of) the TIMES model. Of the LTES documents, 29% use LEAP and 20% use TIMES. Meanwhile, only 8% of scenario-based LT-LEDS documents rely on LEAP, while 25% use (a variation of) TIMES. These models are comparable in scope and ability to cover the variables discussed in Chapter 2, so the use of one model over another does not seem to affect the results of that chapter.

Box 7 **Institutional alignment between LTES and scenario-based LT-LEDS in the same country**

Of all the countries covered in this report, 12 countries are identified to have both scenario-based LT-LEDS and LTES. They are: Canada, Chile, Colombia, Costa Rica, Finland, Guatemala, Indonesia, the Marshall Islands, Mexico, North Macedonia, South Africa and the United States. For these countries, it is possible to look for points where the processes of developing their LTES and scenario-based LT-LEDS were aligned.

Elements that can indicate alignment are first, having a shared publishing institution, and second, using the same modelling tools and scenarios. Of the 12 countries that submitted a scenario-based LT-LEDS and which also have an LTES, Colombia and Finland particularly draw attention in respect of institutional elements. Both countries use common modelling tools and scenarios for their scenario-based LT-LEDS and LTES, which indicates a thorough alignment between both processes and the analytical capacities within the institutions. Finland's scenario-based LT-LEDS and LTES are developed from the same research project on reaching carbon neutrality by 2035. The scenario-based LT-LEDS, which was published a few months after the LTES, references the LTES multiple times and directs the reader to the LTES for more detail on the scenario assumptions. Colombia's LTES was developed separately from their scenario-based LT-LEDS, but the latter heavily references the former. The scenarios and analysis in the Colombian LTES are used as the basis for the country's scenario-based LT-LEDS, and the contribution of the LTES team is acknowledged.

CHAPTER 2

ENERGY TRANSITION ELEMENTS IN LTES AND SCENARIO-BASED LT-LEDS

Having discussed the processes and governance around the development of LTES and scenario-based LT-LEDS, this chapter aims to assess how elements of the energy transition are captured in LTES and scenario-based LT-LEDS. To guide the assessment, the chapter is structured around the elements that are expected to be critical to pathways towards net-zero energy systems.

ELEMENTS OF THE ENERGY TRANSITION

Elements of the energy transition were identified primarily through the discussion and analysis presented in *World energy transitions outlook* (IRENA, 2022c), and elaborated in IRENA's report *Smart electrification with renewables* (IRENA, 2022d). They are mapped according to seven main building blocks, as shown in Figure 5. They are:

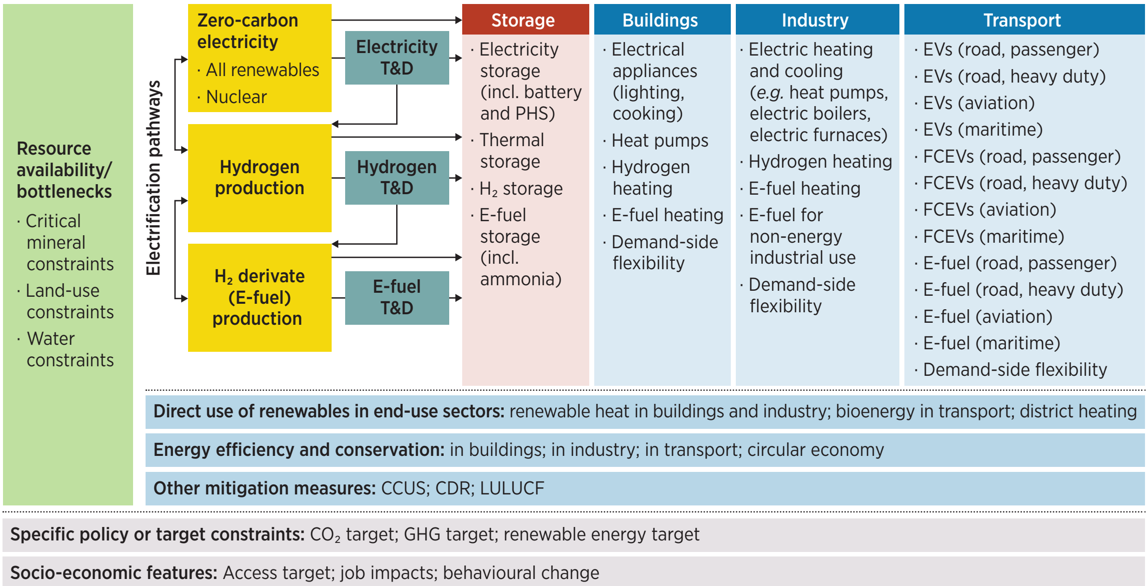
1. Supply block with three sub-blocks (zero-carbon electricity, hydrogen, e-fuel).
2. Transmission and distribution (T&D) block with three sub-blocks (electricity T&D, hydrogen T&D, e-fuel T&D).
3. Storage block.
4. End-use block with three sub-blocks (buildings, industry and transport).
5. Non-electrification block with three sub-blocks (direct use of renewable heat and bioenergy in end use, energy efficiency and conservation, and other mitigation measures).
6. Resource constraint block.
7. Contextual block with two sub-blocks (policy and socio-economic features).

Detailed scenario elements were identified under each block. Box 8 gives a description of each building block. A full list of the elements is provided in the Appendix.

A review of the scenarios used in the LTES and scenario-based LT-LEDS was conducted to assess whether and how these individual elements were included in the respective scenario frameworks. The assessment was conducted using countries' replies to the technical survey, or, when the responses were absent, through IRENA desk research. The focus of the assessment was the inclusion of the elements in the scenario framework, rather than in the scenarios themselves. In other words, the inclusion of certain elements (*e.g.* a particular technology) in the scenario framework is not equivalent to the endorsement of these elements in future scenarios, as any particular technology may be evaluated as unviable in the future pathways. The individual elements in the scenario framework were assessed and categorised under one of the following three options: "quantitative" (when the component was explicitly included in the scenario and it is represented in a quantitative manner); "qualitative" (when the component was represented in the scenario in a qualitative manner as a part of the overall narrative, but not as its own specific option with quantitative parameters); or "not included".

Figure 5 **Schematic presentation of the energy transition elements**

Technical survey intro: Energy transition landscape



Notes: CCUS = carbon capture, utilisation and storage; CDR = carbon dioxide removal; e-fuel = electrofuel; EV = electric vehicle; FCEV = fuel cell electric vehicle; LULUCF = land use, land-use change and forestry; PHS = pumped-storage hydro; T&D = Transmission and distribution.

Source: Adapted from IRENA (2022d).

Box 8 **Description of the energy transition elements**

1. Electricity-based supply block

Electrification of the energy system with renewable-based electricity is a key component of the energy transition. Hydrogen and e-fuels produced with renewable electricity are emerging technologies with potentially wide-ranging implications for the way energy will be used in different end-use sectors in the future.

2. Transmission and distribution (T&D) block

Large-scale electrification requires grid investment and expansion to enable the transition. Indirect electrification through hydrogen and hydrogen derivatives also requires dedicated infrastructure, possibly including refurbished pipelines built for fossil-based fuels.

3. Storage block

Electricity, hydrogen and e-fuel storage enables the efficient use of variable renewable power, such as solar and wind, while providing support to the secure operation of the power system. Thermal storage can decouple heating demand from power generation, leading to more flexibility and reduced need for grid investment.

4. End-use block

The end-use block is broken down into three sub-blocks: buildings, industry and transport. Buildings and industry use electricity directly as a fuel or heat source, and hydrogen and e-fuels as heating fuels. In transport, electricity, hydrogen and e-fuels are used as drivers for mobility in the main forms of transport: passenger cars, heavy-duty trucks and buses, aircraft and ships. Demand-side flexibility is a component of all end-use sectors and is a crucial part of a successful energy transition.

5. Non-electrification block

Direct use of renewables in buildings and industry includes heating from wood-fired stoves, and in transport through the use of biofuels. Energy efficiency encompasses all kinds of energy-saving policies and behaviours, as well as conservation of natural resources through the circular economy. Other mitigation measures include measures that remove carbon dioxide, either during the generation process (CCUS), directly from the air (CDR) or through carbon sinks (LULUCF).

6. Resource constraint block

The energy transition is constrained by the availability of natural resources. A shortage of critical minerals affects the construction of power grids, solar panels and wind turbines. The availability of land affects generation that relies on natural resources as fuel and forms of energy generation that require large surface areas, and water scarcity affects systems dependent on using water as a driver, *e.g.* hydropower.

7. Contextual block

Elements that give context to the energy transition are policy targets, such as a GHG target or renewable energy targets, and socio-economic impacts of the transition, such as impacts on jobs, public health and behavioural changes.

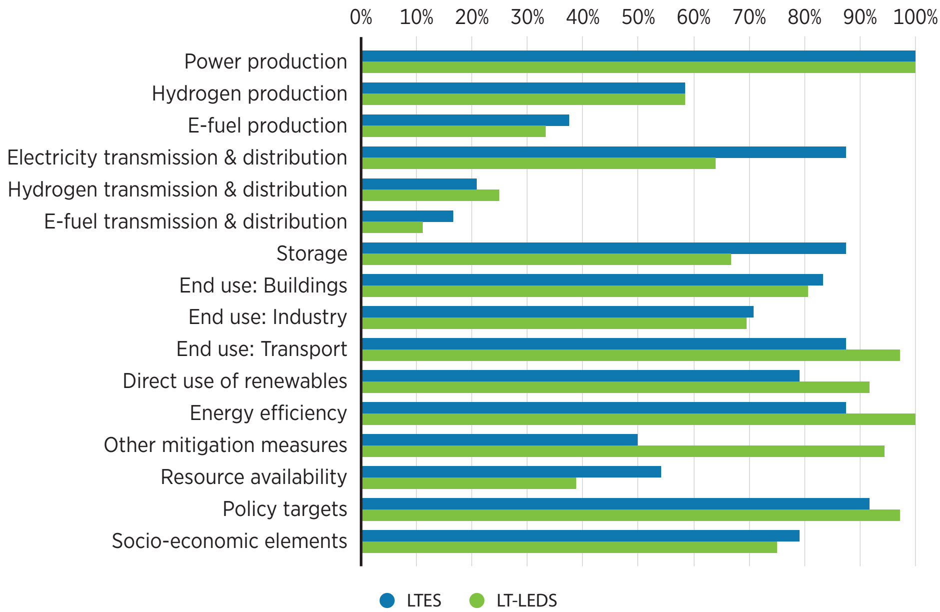
GENERAL COMPARISON OF COVERAGE OF ENERGY TRANSITION ELEMENTS

Figure 6 summarises the representation of energy transition elements in each category of LTES and scenario-based LT-LEDS in this analysis.[8] Generally, LTES represent power sector-related elements, such as power production (1.1), electricity T&D (2.1) and storage (3) more comprehensively than scenario-based LT-LEDS. The remaining blocks, particularly the end-use sector blocks (4.1-4.3), and the non-electrification blocks (5.1-5.3), are addressed in more detail in the scenario-based LT-LEDS. In both LTES and scenario-based LT-LEDS, the inclusion of e-fuels production and T&D (1.3 and 2.3) and hydrogen T&D (2.2) is predominantly done in a qualitative manner. Both LTES and scenario-based LT-LEDS address the socio-economic elements (7.2) in a more qualitative manner, while scenario-based LT-LEDS also address storage (3) and resource constraints (6) in a more qualitative manner.

As shown in the subsequent sections, scenario-based LT-LEDS tend to show a wider range of emerging technologies than LTES, possibly highlighting that LTES may be more conservative or less explorative due to their role in the energy policy making processes within government, their relatively shorter time horizon in some cases, and due to current LTES not explicitly having carbon neutrality as an objective, unlike scenario-based LT-LEDS.

[8] *The percentages represent the share of documents that include a given element under the respective categories.*

Figure 6 **Representation of energy transition elements by category in LTES and scenario-based LT-LEDS scenarios**

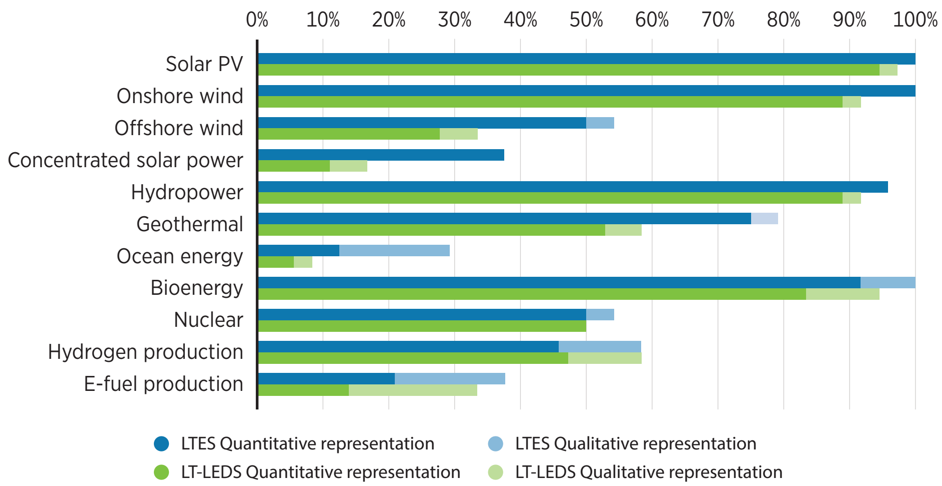


DETAILED COMPARISON OF COVERAGE OF ENERGY TRANSITION ELEMENTS

Supply (1)

This block features the following zero-carbon power generation technologies: solar PV, on- and offshore wind, concentrated solar power, bioenergy, hydropower, geothermal energy, ocean energy and nuclear energy. It also includes the production of hydrogen and e-fuels, which are hydrogen-derived synthetic fuels. Figure 7 summarises the results of the assessment of the elements under this block.

Figure 7 **Representation of power generation and hydrogen and e-fuel production in LTES and scenario-based LT-LEDS scenarios**



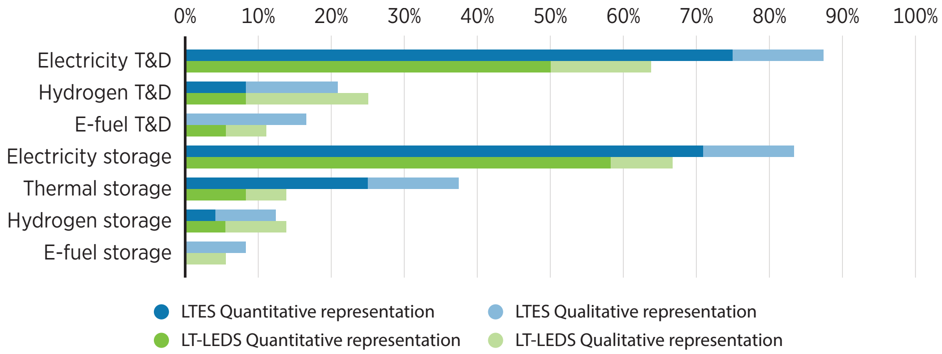
The survey results indicate that the LTES included in this report tend to cover power production variables more comprehensively than the scenario-based LT-LEDS. The most common renewable power technologies that are addressed are solar PV and onshore wind, followed closely by bioenergy and hydropower. The remaining technology options may be dependent on the availability of natural resources, as well as the political climate.

Of the LTES and scenario-based LT-LEDS surveyed, 58% of both types of documents include hydrogen production in their scenarios, with the LTES scenarios tending to feature hydrogen slightly more quantitatively than the LT-LEDS. E-fuels derived from hydrogen, such as ammonia and methanol, are included in only 38% and 33% of scenarios in LTES and scenario-based LT-LEDS, respectively.

Transmission and distribution (2) and storage (3)

Blocks 2 and 3 feature the infrastructure to transport and store the four main forms of (clean) energy: electricity, hydrogen, e-fuels and heat. Figure 8 summarises how these elements are represented in LTES and scenario-based LT-LEDS scenarios.

Figure 8 **Representation of power, hydrogen and e-fuel transmission & distribution and storage in LTES and scenario-based LT-LEDS scenarios**



Generally, electricity T&D and storage are well covered in LTES, with scenario-based LT-LEDS covering them to a lesser extent. The fact that 64% of the scenario-based LT-LEDS still cover electricity T&D and 66% cover electricity storage reflects the significance countries place on electrification in the overall clean energy transition. The thorough analysis of electricity grids in the LTES surveyed is commendable.

Transport and distribution systems for hydrogen and e-fuels, in contrast, is not addressed as often in either LTES or scenario-based LT-LEDS. When they are addressed, it is generally in qualitative terms rather than quantitatively. This observation also holds for the storage of these fuels. The relatively frequent qualitative inclusion of these elements may reflect high uncertainty and data scarcity in respect of relatively immature technologies.

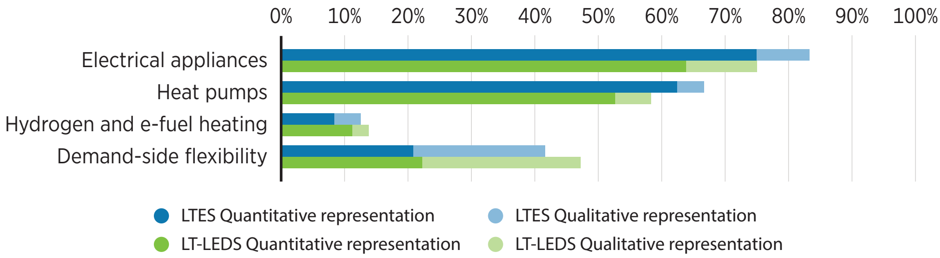
Finally, thermal storage is assessed in 38% of the surveyed LTES and only 14% of the scenario-based LT-LEDS.

End-use applications (4)

The end-use block is split into three sub-blocks: buildings, industry and transport. Figure 9 shows the representation of electrification and other energy transition elements in the sub-block for the building sector.

Electrification of buildings (4.1)

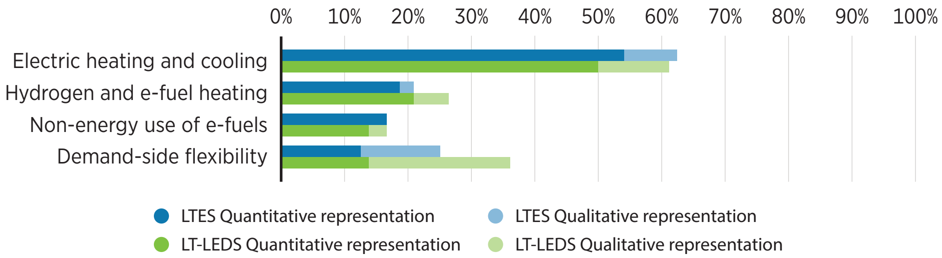
Figure 9 **Representation of end-use applications in the buildings sector in LTES and scenario-based LT-LEDS scenarios**



Electricity use for household appliances is covered well in both LTES and scenario-based LT-LEDS. Electric heating and cooling in buildings is included in around 67% of LTES and 58% of scenario-based LT-LEDS. The use of hydrogen and e-fuels for heating is covered by a minority of the scenarios assessed in this report, and more by scenario-based LT-LEDS than LTES. This is also the case for demand-side flexibility: flexibility in the buildings sector is featured in 42% of LTES and 47% of scenario-based LT-LEDS.

Electrification of industry (4.2)

Figure 10 **Representation of end-use applications in the industry sector in LTES and scenario-based LT-LEDS scenarios**



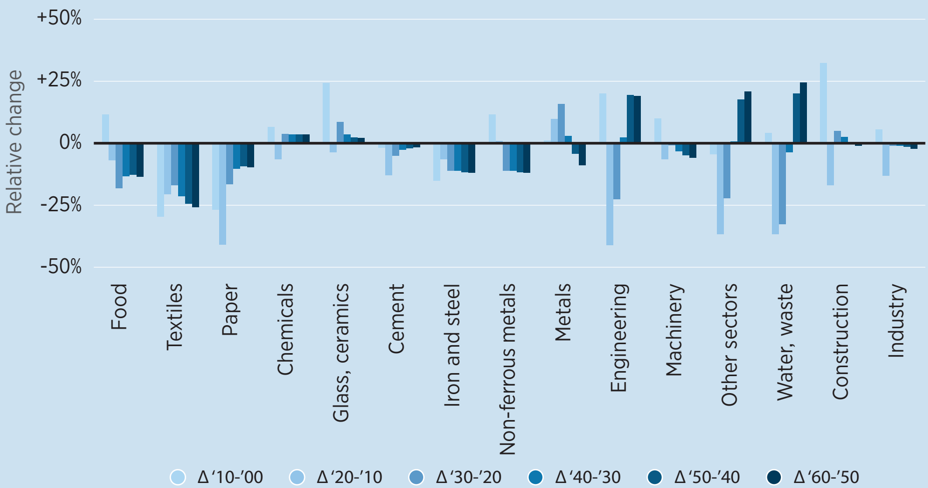
Electric heating and cooling in industry is included by around 60% of both LTES and scenario-based LT-LEDS. The use of hydrogen and e-fuels for heating is covered by a minority of the scenarios assessed in this report, however, and as with the results for buildings, more by scenario-based LT-LEDS than LTES. E-fuels for non-energy uses (such as feedstock) were assessed even less, appearing in less than a fifth of either LTES or scenario-based LT-LEDS.

As for or demand-side flexibility in the industrial sector, it is included in 36% of scenario-based LT-LEDS and only 25% of LTES. This report assessed general coverage of the industrial sector as a whole, but some countries included a more detailed assessment of industrial sub-sectors in their planning documents. For examples, see Box 9.

Box 9 **Industrial sub-sectors in energy planning scenarios**

While the survey for this report assessed general coverage of the industrial sector, some countries included a deeper dive into their national industries and their various sub-sectors. One example is Switzerland's technical analysis underlying their scenario-based LT-LEDS, which contains a detailed overview of the main subsectors of Swiss industry. It forecasts general production indices for each sub-sector, and the relative change in energy use by sector over time. Performing such an analysis of specific industries can paint a better picture of how scenarios can affect different sectors and help a country better anticipate the effects of its energy transition policies. As can be seen from Figure 11 below, the aggregate *Industry* category shows relatively minor changes, but the results for the subsectors indicate significantly larger changes, both upwards and downwards compared to today. Including only an aggregate category for "industry" would have missed these effects on the subsectors.

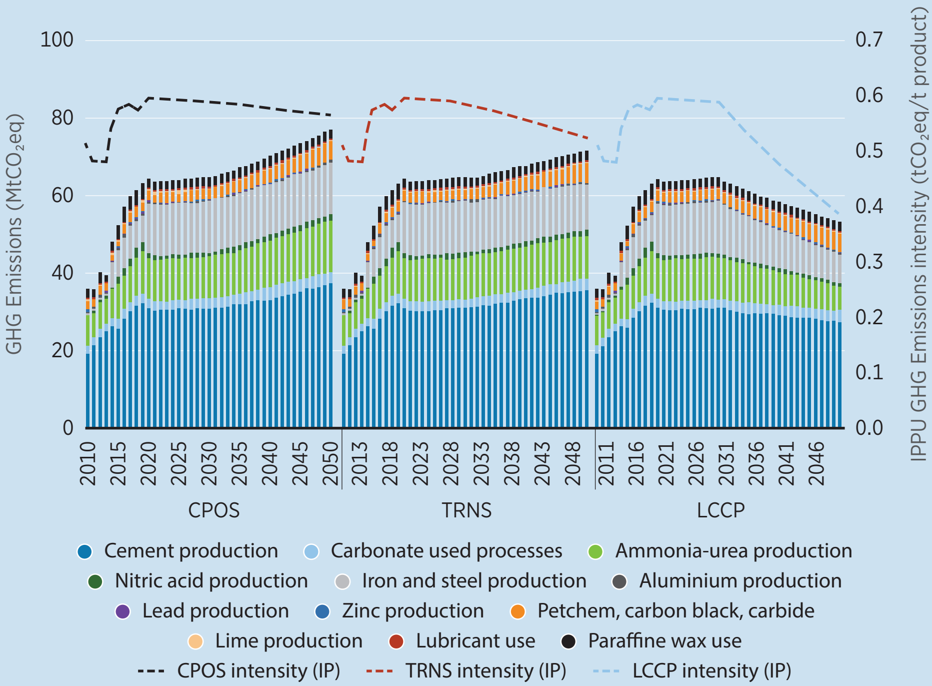
Figure 11 **Energy reference area in different industrial sub-sectors in Switzerland's LT-LEDS**



Source: Federal Office of Energy, Switzerland (2021).

Another example of a more granular assessment of national industry can be found in Indonesia's LT-LEDS. It models greenhouse gas emissions by industrial sub-sector under their three scenarios, with three different levels of energy intensity. This allowed them to discover the sectors in which certain decarbonisation measures would have the most impact. Figure 12 shows the emissions from industrial subsectors under the three scenarios included in Indonesia's LT-LEDS: the *Current Policy Scenario* (CPOS), *Transition Scenario* (TRNS) and *Low Carbon Scenario Compatible with Paris Agreement Target* (LCCP). As the graph indicates, the three scenarios affect industrial subsectors differently: under TRNS, the ratio of emissions from the different sectors remains similar to that under CPOS, but under LCCP especially the ammonia-urea and iron and steel sector emissions are being cut more than the others. This example shows how including industrial sub-sectors in scenarios can help identify immediate opportunities when it comes to decarbonisation policies.

Figure 12 **GHG emissions development and projections Indonesia's LT-LEDS scenarios**



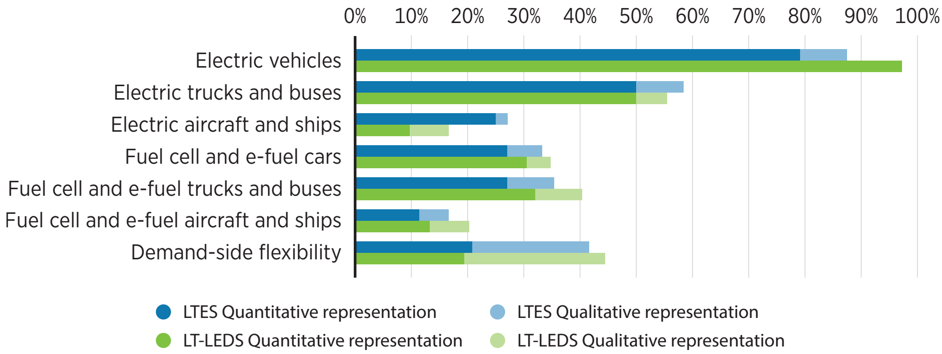
Source: Ministry for Environment and Forestry, Indonesia (2021).

Including a comprehensive overview of the industrial sector and its sub-sectors aids the general understanding of the current situation, as well as painting a better picture of how individual scenarios can affect different industry sub-sectors. It also improves the understanding of how the different industry sub-sectors interact with the wider energy system: for some sub-sectors direct electrification might be the optimal way to decarbonise, while for others it might be indirect electrification or capturing the carbon emitted during the production process. Assessing individual sub-sectors and investigating how different scenarios affect them can help a country better anticipate the effects of its energy transition policies and the trade-offs required to accelerate the transition in each area.

Transport (4.3)

As can be seen in Figure 13, the coverage of elements related to the transport sector is quite similar for LTES and scenario-based LT-LEDS, with the latter generally representing the elements slightly more comprehensively than LTES.

Figure 13 **Representation of end-use applications in the transport sector in LTES and scenario-based LT-LEDS scenarios**



Electric vehicle applications for passenger transport are assessed in 88% of LTES and 97% of scenario-based LT-LEDS reflecting the importance of this technology in the energy transition. For passenger transport, about 46% of LTES and 50% of scenario-based LT-LEDS included fuel cell vehicles, while cars powered by e-fuels are included by 21% of LTES and 22% of scenario-based LT-LEDS.

As regards the coverage of alternative fuels for heavy-duty vehicles like freight trucks and buses, 58% of LTES and 56% of scenario-based LT-LEDS include an assessment of electrically powered vehicles. Heavy-duty vehicles running on hydrogen are covered by 53% of scenario-based LT-LEDS and 46% of LTES, while heavy-duty vehicles with e-fuels as their main energy source are included by only 25% of LTES and 28% of scenario-based LT-LEDS.

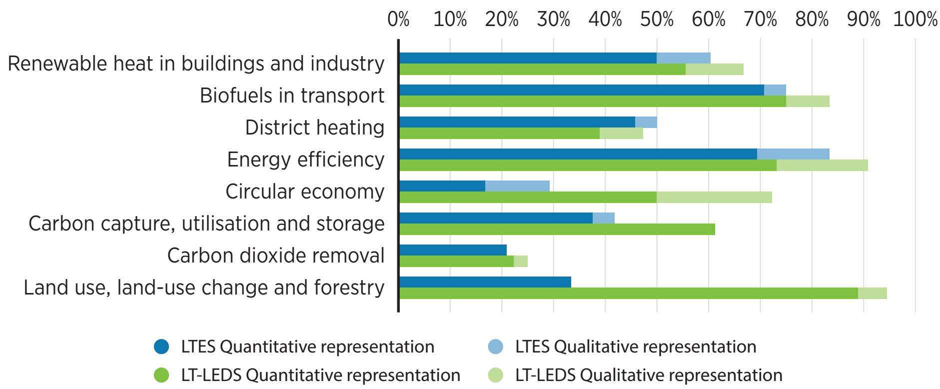
A similar pattern emerges for alternative fuels for aviation: electric aircraft are covered by a similar share of LTES and scenario-based LT-LEDS (21% and 17% respectively). Aircraft fuelled by hydrogen or e-fuels have limited coverage in scenario-based LT-LEDS (17-28%), but even less so in LTES (13-17%). Maritime ships powered by electricity are included in 33% of LTES and 17% of scenario-based LT-LEDS. Ships running on hydrogen and e-fuel are addressed by just under 20% of both LTES and scenario-based LT-LEDS scenarios.

Demand-side flexibility in the transport sector, for example in the form of smart charging, is included by 42% of LTES and 44% of scenario-based LT-LEDS. A significant share of the scenarios that include it do so qualitatively rather than quantitatively.

Non-electrification pathways block (5)

Figure 14 summarises how the non-electrification elements are represented in LTES and LT-LEDS scenarios.

Figure 14 **Representation of non-electrification elements in LTES and scenario-based LT-LEDS scenarios**



Direct use of renewables (5.1)

This block features energy transition elements outside electrification, such as the direct use of renewables in end-use sectors. Direct use of renewables is prominent in the buildings and industrial sectors in the form of heating with biomass. In the transport sector, renewables are used directly in the form of biofuels, such as bio-ethanol and biodiesel.

Biofuel use in the transport sector is generally well captured in both LTES and scenario-based LT-LEDS (75% and 83%, respectively). Comparing this with the electrification options discussed above for the transport sector, biofuels are more comprehensively assessed as an alternative transport fuel than hydrogen or hydrogen-based e-fuels. A similar observation can be made for the industrial and buildings sectors, where the direct use of renewables in heating (*e.g.* wood-fired stoves) is analysed more comprehensively than heating with hydrogen and e-fuels. Generally, the direct use of renewables in end-use sectors is slightly better captured in scenario-based LT-LEDS than LTES.

District heating is addressed in 50% of the LTES and 47% of scenario-based LT-LEDS scenarios. This makes it a less-comprehensively assessed network than the electricity grid, but more than the hydrogen and e-fuel networks.

Energy efficiency and conservation (5.2)

Energy efficiency is assessed quantitatively in most of the scenarios in all planning documents analysed, but more so by scenario-based LT-LEDS than LTES. Another aspect of saving energy is the concept of a circular economy, which reduces the need for the production of completely new items and therefore saves energy and resources indirectly. Aspects of circular economy are represented in 72% of scenario-based LT-LEDS, of which the majority do so in a quantitative manner. LTES, conversely, less commonly include the circular economy in their scenarios: only 29% of the LTES scenarios do so, with 17% doing so quantitatively.

Other mitigation options (5.3)

Among the measures that directly reduce the concentration of CO_2 in the atmosphere, LULUCF is more extensively covered by scenario-based LT-LEDS: almost all do so, and the vast majority of those in a quantitative manner. In contrast, only 33% of LTES include LULUCF. CCUS is included by 61% of scenario-based LT-LEDS and 42% of LTES. CDR is covered least: 25% of scenario-based LT-LEDS and 21% of LTES do so.

Resource constraint block (6)

Figure 15 **Representation of natural resource constraints in LTES and scenario-based LT-LEDS scenarios**

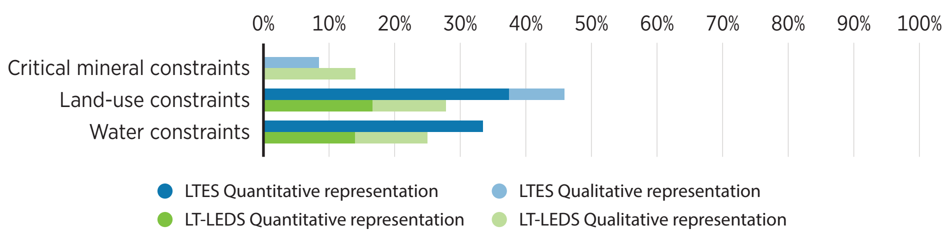


Figure 15 demonstrates how the topic of natural resource availability tends to be left uncovered by the majority of LTES and scenario-based LT-LEDS. Land-use constraints are addressed by 46% of LTES and 28% of scenario-based LT-LEDS, and water constraints by 33% of LTES and 25% of scenario-based LT-LEDS. The issue of availability of critical minerals is essential to the energy transition, but is rarely included by either: 14% of scenario-based LT-LEDS and 8% of LTES mention it qualitatively, and no scenario addresses it quantitatively.

This might partly reflect the difficulty in linking international mining and trade uncertainties into a national energy planning framework. More on this topic can be found in Box 10.

Box 10 **Modelling critical mineral constraints**

The growth in demand for minerals and materials needed for the energy transition is putting a strain on supply. Critical material availability might not halt the energy transition on its own, but key bottlenecks, namely in mining and processing, must be addressed. New capacity is not the only problem: the geographical concentration of where the mining and the processing is being done is another concern for countries.

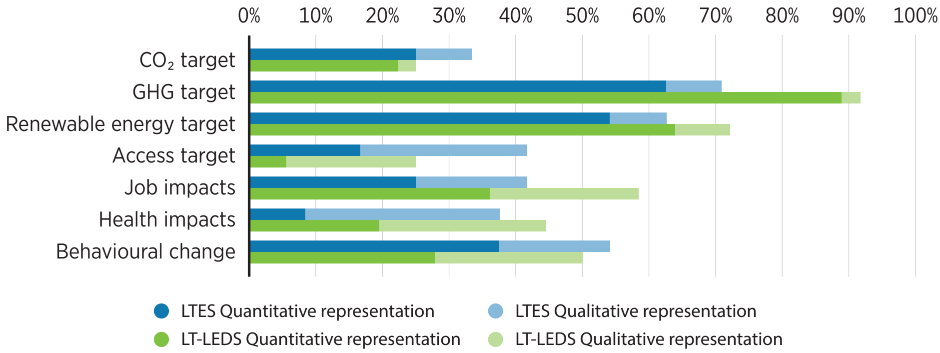
Modelling natural resource constraints is a challenging undertaking, particularly in respect of constraints on a resource that is demanded globally, such as critical minerals. Modelling the availability of critical minerals requires a global supply chain model that can be linked to other models. Examples of such a model include that used by the US Department of Defense and Argonne's Global Critical Materials model (GCMat), which is used by the US Department of Energy (Riddle *et al.*, 2021). A further complication when modelling critical mineral constraints is the availability of public data. A 2020 study has shown that some critical metals lack long-term demand outlooks, and aspects of the circular economy like reusing and recycling resources are often overlooked (Takuma Watari *et al.*, 2020). In addition to these questions are uncertainties around how future demand for critical minerals will be affected by innovation. Equipment design generally does not consider scarcity, so innovations around the substitutability of certain resources might alter the demand projections for critical minerals (Gielen, 2021).

All these factors help explain why including critical mineral constraints in scenarios for long-term energy planning might be complicated. However, in view of the many applications of critical minerals in equipment throughout the energy supply chain, their omission from energy system modelling can be considered a blind spot that may affect the success or speed of the global energy transition.

Contextual block (7)

Figure 16 summarises how the contextual elements of policy targets and socio-economic factors are represented in LTES and LT-LEDS scenarios.

Figure 16 **Representation of contextual elements in LTES and scenario-based LT-LEDS scenarios**



Policy or target constraints (7.1)

Emission targets usually involve an umbrella GHG target, but countries can also include a specific CO_2 target that doesn't affect the emissions of other greenhouse gases. Most scenarios (over 90% of scenario-based LT-LEDS and 71% of LTES) include a GHG target, while 25% of scenario-based LT-LEDS and 33% of LTES include a specific CO_2 target. A renewable energy target, either in the shape of a target for installed capacity (MW or GW) or a target for a share of generation to be met by renewable energy, is included by 62% of LTES and 72% of scenario-based LT-LEDS scenarios.

Socio-economic elements (7.2)

Generally, scenario-based LT-LEDS cover the socio-economic impacts of the energy transition more fully than LTES, although they are not featured in a large majority of either. Around half of scenario-based LT-LEDS address job impacts (58%), behavioural change (50%) and health impacts (44%), whereas 42% and 54% of LTES cover job impacts and behavioural changes and only 38% of LTES include health impacts. Health impacts are addressed predominantly in a qualitative manner in both LTES and scenario-based LT-LEDS. Energy access targets are included in 25% of scenario-based LT-LEDS and 42% of LTES, mainly by countries in Latin America and Africa.

COMPARISON OF SCENARIO COVERAGE IN 12 COUNTRIES

As discussed in the preceding sections of this chapter, LTES tend to contain more detailed information than scenario-based LT-LEDS scenarios on variables directly related to the production, transmission, distribution and storage of different types of energy.

To explore this point further, the comprehensiveness of these variables was assessed for the 12 countries that have both a scenario-based LT-LEDS as well as in LTES. These countries are Canada, Chile, Colombia, Costa Rica, Finland, Guatemala, Indonesia, the Marshall Islands, Mexico, North Macedonia, South Africa and the United States. As discussed in Chapter 1, this report uses a simple indicator of comprehensiveness that was discerned by quantifying the survey answers that were discussed in the sections above. Variables that were included quantitatively are assigned a 3, those included qualitatively a 2, and variables that were not included in the scenarios are given a 1. The average of the variables in a particular section can then indicate comprehensiveness: the higher the average, the higher the level of detail of the variables and their inclusion in the scenarios.

The findings in Chapter 1 demonstrate that planning documents published by an integrated ministry or multiple institutions tend to have higher levels of comprehensiveness in their scenarios. Of the planning documents of the 12 countries mentioned above, only the LT-LEDS of Colombia, Costa Rica, Finland, the Marshall Islands and the United States are published by an integrated ministry or multiple institutions, with the remaining LT-LEDS and all LTES being published by a single (non-integrated) ministry or institution. To discover if the findings from Chapter 1 hold for these individual cases, the exercise from Chapter 1 can be repeated specifically for the variables that scenario-based LT-LEDS clearly represent less than LTES: the variables related to energy production, transmission, distribution and storage. Table 6 below shows the results, with the countries whose LT-LEDS are published by an integrated ministry or multiple institutions in bold).

As the table shows, the LT-LEDS from the highlighted countries have, on average, higher scores than the ones from the remaining countries. Among the highlighted countries are also the only countries where the LT-LEDS has a higher score than the LTES – in the cases of Costa Rica, the Marshall Islands and the United States.

Table 6 **Comparison of comprehensiveness of LTES and LT-LEDS on variables relating to energy production, transmission & distribution, and storage**

Country (in bold if LT-LEDS is published by an integrated ministry or multiple institutions)	**Score for LTES**	**Score for scenario-based LT-LEDS**
Canada	2.25	2.10
Chile	2.13	1.28
Colombia	2.01	**1.91**
Costa Rica	1.40	**1.72**
Finland	2.29	**2.17**
Guatemala	1.44	1.39
Indonesia	1.60	1.36
Marshall Islands	1.52	**1.59**
Mexico	1.53	1.39
North Macedonia	1.54	1.51
South Africa	1.63	1.43
United States	1.65	**1.99**

Although the sample size is small, these preliminary findings might suggest that alignment of LTES and scenario-based LT-LEDS processes may improve the quality of a country's scenario-based LT-LEDS data on energy production, transmission, distribution, and storage variables. However, it is important to note that the sample size was small and further research is needed to confirm these findings.

Box 11 **Potential trade-offs between model complexity and coverage**

The previous sections have discussed in detail which variables are included quantitatively or qualitatively in LTES and scenario-based LT-LEDS scenarios. While including more variables will lead to a more comprehensive overview of the energy transition and its consequences, it must be acknowledged that adding to a model's coverage can increase its complexity. Highly complex models tend to be harder to interpret, have a higher possibility for introducing (human) error, can increase input data requirements and might require exponentially higher computational power. All these factors can lead to higher barriers for including more variables in scenarios, particularly for countries with less experience, capacity and resources in energy system modelling. An alternative approach could be a collaboration with external partners who specialise in a specific (sub-)sector, and to combine the two analyses on a technical level. This would allow the scenarios to capture these dimensions while keeping the complexity of all models involved manageable.

CONCLUSION

Governments need to act immediately to address climate change, with all stakeholders on board to drive the energy transition. It is well understood that this is not solely an energy challenge, but a radical societal and technical transformation that touches upon all facets of governance and investment strategies. Energy policy planning needs to expand its scope to consider broader changes surrounding the energy sector and the implications for wider sectors of the economy. Climate policy also needs to consider alignment with energy policy objectives to ensure that energy stakeholders are on board with the implementation of climate goals.

While scenario-based LT-LEDS and LTES may be developed with different planning time horizons and sectoral coverage, reflecting diverging priorities, net-zero goals under the Paris Agreement demand that the scope of LTES expands to cover longer planning time horizons and broader sectoral coverage than they have traditionally. LT-LEDS present opportunities for energy and climate policy making to come closer. Institutional co-ordination in LTES and LT-LEDS development allows climate policy to incorporate the energy sectors' objectives into the LT-LEDS. Updating both LTES and LT-LEDS regularly allows for mutual learning for both documents, and for bridges to be built between the two processes.

It is therefore encouraging to see that the analysis of scenario-based LT-LEDS and LTES in this report appears to show a generally good level of alignment. This conclusion could be explained by several factors, but we primarily focus on the "scenario factor"- that is, we chose to assess only those LT-LEDS that are based on scenarios. To develop scenario-based LT-LEDS that address long-term net-zero targets, a scientifically robust assessment methodology needs to be deployed – typically including some form of modelling. The adoption of scientifically robust assessment is often accompanied by scientifically robust traceability and accountability of scenario outputs, which allows greater scrutiny and transparency. In countries where the government possesses the capacity to manage the development of LTES – as opposed to outsourcing to third parties – an energy ministry or a dedicated energy planning institution can serve as the technical focal point for developing the LT-LEDS in co-ordination with the ministry responsible for environmental and climate policy.

A preliminary conclusion from this is analysis is that a wider adoption of scenario-based planning approaches for LT-LEDS can lead to more robust strategies than LT-LEDS without scenarios. This is due to the fact that having a scenario framework can more easily lead to dialogue among stakeholders on a concrete quantitative basis, reflecting data and realities on the ground, and receiving greater buy-in from government institutions responsible for implementation. Further research can be done to compare LT-LEDS to assess the role of scenarios in providing analytical rigour and robust inputs.

The section below uses observations from the analysis in this report and findings from previous LTES Network discussions and findings to provide further holistic system-wide recommendations for governments on how to enhance and align their different sectoral plans at an institutional and technical level.

Figure 17 **Guidelines for developing effective LTES and scenario-based LT-LEDS**

Co-ordinate	Ensuring **institutional co-ordination within the government sector** when developing long-term scenarios with energy, climate and other institutions can help **leverage diverse sectoral expertise** for a broader scope, ensure high-quality data and quality assurance, and avoid duplication of work. **Scenarios contribute to this**.
Engage	Engaging a **broad range of stakeholders** and dedicating special resources can ensure **participatory and inclusive inputs** into the planning document and can result in more robust data, more buy-in from different stakeholders, and effective communication of scenarios with different actors.
Develop	Developing scenarios that go beyond traditional energy scenarios by including **socio-economic impacts, future technologies and robust power transmission and distribution** can capture the cost of the transition, highlight its positive human impacts and address immediate social and economic concerns.
Communicate	Producing **strong communication and outreach strategies** for LTES and LT-LEDS allows them to act as powerful drivers of technology transfer and a signal for technology developers, investments, and cross-border collaboration.
Implement	Leveraging the ambitions and visibility of LT-LEDS as a **driver for policy making, legislation and regulation** can ensure their ambitions are **enshrined in law** and can positively affect implementation by both government and non-government sectors.

INSTITUTIONAL OBSERVATIONS

Linking and streamlining scenario development across different publications can harmonise results and targets

The process of scenario development itself can work as a co-ordination mechanism between LTES and scenario-based LT-LEDS, while making use of sectoral expertise within different institutions.

Survey results showed that in cases where scenarios are developed and used with the intention of supporting plans in different documents, it creates consistency between targets and milestones in energy and climate plans and allows government institutions to send a synchronised signal on medium- to long-term plans and regulations. This can be strengthened by further developing scenario-building capacity and departments in government institutions to ensure consistency, ownership and quality assurance in the use of scenarios. Alternatively, using scenarios from a previously published planning document also achieves the goal of aligning different planning processes, and frees up capacity to dedicate to other parts of the planning document.

Enhancement of institutional co-ordination across energy and climate sectors – and beyond – is vital for actionable scenario-based LT-LEDS

Formal institutional arrangements are key to ensuring policy coherence and stakeholder engagement in support of holistic scenario development for both LTES and scenario-based LT-LEDS.

A lack of co-ordination between scenario-based LT-LEDS and the energy planning process – as well as the lack of buy-in from the relevant ministries (including finance, infrastructure, transport and other crucial sectors) and other stakeholders – can potentially undermine the relevance of scenario-based LT-LEDS to the implementation of decarbonisation efforts, either by weakening policy effectiveness or misdirecting investment strategies. Institutional set-ups favouring co-ordination support the operationalisation of Paris Agreement goals. Co-operation can take the form of inter-ministerial committees or taskforces, or even integrated ministries that cover climate and energy portfolios, and potentially others. Committees can be independent or fully integrated within existing political institutions.

Utilising scenario-based LT-LEDS as a policy and legal driver creates an actionable guiding document for national energy and economic development

Energy plans, net-zero strategies and scenario-based LT-LEDS can all be useful guiding tools for policy making and planning investment. However, legislating targets with direct reference to these documents and developing regulations accordingly allows for concrete implementation on the ground.

Government-wide collaboration on energy planning should also allow ministries to update legislative and regulatory frameworks that support mitigation in the energy sector. More formal processes, such as enacting targets and milestones from energy and climate plans into law, should allow scenario-based LT-LEDS to drive the clean energy transition on the ground. This should then allow the government to identify and correct misalignments between existing legislation and climate goals, as well as catalogue existing legal frameworks that may support new energy sector plans. It will also provide a concrete target from which planners can backcast possible trajectories .

Expanding stakeholder consultation across both LTES and scenario-based LT-LEDS processes can increase buy-in from different actors and improve input data

Broad stakeholder consultations and feedback collection, especially in economy-wide plans such as scenario-based LT-LEDS, allow long-term energy scenarios to adapt and reflect the changing landscape of energy sector actors.

The survey considers stakeholder involvement throughout the process of scenario development, from input on defining the parameters to the translation of results into public policy. While the elaboration of many scenario-based LT-LEDS included some form of consultation, a stronger and more robust participatory process is likely to increase trust and legitimacy among stakeholders that are normally excluded, while allowing for space to explore agreements and convergences on the pathways in scenarios. Discussions with stakeholders can also help governments improve their understanding of both how energy sector actors’ behaviour is likely to change, and the corresponding data that can be used as inputs to these scenarios.

TECHNICAL OBSERVATIONS

Engaging different levels of power system planning in scenario-based LT-LEDS can add more detailed and accurate insights concerning the cost of the energy system transformation

Engaging power system planners, such as utilities, and transmission and distribution system operators, can be useful to reflect the challenges facing the power system and its current transformation more accurately.

Scenario-based LT-LEDS survey results were generally less robust than LTES in quantitatively assessing production, transmission and distribution elements of the electricity system. This may lead to further uncertainty on power system behaviour in the medium and long term, which could potentially be avoided by including inputs from different levels of power system planning into the scenario development process of scenario-based LT-LEDS. This can be done through extensive consultations with system operators and incorporating input from their own analysis.

Enhancing the technical scope of both scenario-based LT-LEDS and LTES will be critical to avoid inefficient investment in new technologies for hard-to-decarbonise sectors

Scenarios need to better reflect the potential for, and cost of, generation, transmission, storage and use of green hydrogen, e-fuels for aviation and maritime shipping, and demand-side flexibility. This should increase understanding of how investment can be targeted at specific sectors.

Green hydrogen, e-fuels and demand-side flexibility are rightly seen as potentially beneficial solutions to the challenge of decarbonising sectors such as energy-intensive industry and long-distance transport. However, a considerable majority of both current scenario-based LT-LEDS and LTES do not adequately account for their various infrastructure needs, treating them largely in a qualitative way, or not including them at all. This leads to a significant risk of underestimating their costs, and thus overestimating their potential for application, resulting in inefficient investment.

Although the current state of these technologies' representation is understandable given their relative novelty, there are good practices available for countries to learn how to integrate them better into their scenarios and planning processes. Highlights show, for example, that having a (separate) national strategy for a part of the energy system (hydrogen, e-fuels, industry end use, etc.) can help to collect necessary sectoral data, which can then be used as inputs for wider scenario-based LT-LEDS and LTES, increase understanding of the potential limits of new technologies against more established solutions, and encourage development and innovation. On top of that, more analyses on new technologies should continue to be conducted to provide additional reliable data.

Inclusion of socio-economic factors in scenario analysis is key for a successful transition

Omitting socio-economic variables when assessing the energy transition and renewable energy uptake over the long term might lead to the positive and potentially negative human and welfare impacts of the transition being overlooked.

LTES and scenario-based LT-LEDS in the analysis mostly overlooked assessment of the socio-economic impacts of the energy transition within the scenarios, possibly due to technical limitations in commonly used analytical tools and models. Quantitatively assessing the increase in renewable energy jobs and the effect of clean air on public health can be a useful communication tool to justify a clean and just transition. It can also serve as an important guide for short- and medium-term policy making by identifying and minimising risks to communities (*e.g.* by establishing milestone years for economic diversification and job transition programmes) and addressing crucial questions on affordability, equity and quality of life for affected communities.

REFERENCES

BEIS, United Kingdom (2021), *UK Net Zero Strategy – Build Back Greener*, LT-LEDS, Department of Business, Energy and Industrial Strategy, United Kingdom of Great Britain and Northern Ireland, https://unfccc.int/sites/default/files/resource/UK%20Net%20Zero%20Strategy%20-%20Build%20Back%20Greener.pdf.

Climate Analytics (2022), *Long Term Strategies: Low Carbon Growth, Resilience and Prosperity for Least Developed Countries*, p. 54, https://climateanalytics.org/media/lts_in_ldcs_ca_final_15_july_2022.pdf (accessed 23 November 2022).

Costa Rica Gobierno de Bicentenario (2019), *Plan Nacional de Descarbonización 2018-2050*, San José, Costa Rica, https://cambioclimatico.go.cr/wp-content/uploads/2019/02/PLAN.pdf.

Costa Rican Institute of Electricity (2021), *Plan de Expansión de la Generación Eléctrica 2020–2035*, LTES, Instituto Costarricense de Electricidad, Costa Rica, www.grupoice.com/wps/portal/ICE/electricidad/proyectos-energeticos/plan-de-expansion.

DEA (2020), *Denmark's Energy and Climate Outlook 2020*, Danish Energy Agency, https://ens.dk/en/our-services/projections-and-models/denmarks-energy-and-climate-outlook.

DOE (2018), *Philippine Energy Plan 2018-2040*, Department of Energy, Republic of the Philippines.

Environment Agency of Germany (2021), *Projektionsbericht 2021*, LTES, German Environment Agency (UBA), Germany, www.umweltbundesamt.de/sites/default/files/medien/372/dokumente/projektionsbericht_2021_uba_website.pdf.

Federal Ministry for Climate Protection, Austria (2020), *Long-Term Strategy 2050*, LT-LEDS, Federal Ministry for Climate Protection, Republic of Austria, https://unfccc.int/sites/default/files/resource/LTS1_Austria.pdf.

Federal Ministry of Economic Affairs and Climate Action, Germany (2020), *Integrated National Energy and Climate Plan*, LTES, Federal Ministry of Economic Affairs and Climate Action, Germany.

Federal Ministry for Finance, Germany (2021), "Immediate climate action programme for 2022 - Federal Ministry of Finance", Bundesministerium der Finanzen, www.bundesfinanzministerium.de/Content/EN/Standardartikel/Topics/Priority-Issues/Climate-Action/immediate-climate-action-programme-for-2022.html (accessed 16 December 2022).

Federal Office of Energy, Switzerland (2021), *Switzerland's Long-Term Climate Strategy*, LT-LEDS, Swiss Federal Office of Energy, Switzerland https://unfccc.int/sites/default/files/resource/LTS1_Switzerland.pdf.

Gielen, D. (2021), *Critical Materials for the Energy Transition*, International Renewable Energy Agency (IRENA), Abu Dhabi, https://irena.org/Technical-Papers/Critical-Materials-For-The-Energy-Transition.

IDDRI (2021), *A Country-Driven Perspective on Long-Term Low-Emission Development Strategies (LT-LEDS) – Implications for a COP26 Decision Text or Outcome*, IDDRI, www.iddri.org/en/publications-and-events/study/country-driven-perspective-long-term-low-emission-development (accessed 4 November 2022).

IRENA (2022a), *Scenarios for the Energy Transition: Experience and Good Practices in Latin America and the Caribbean*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2022/Jul/Scenarios-for-the-Energy-Transition-LAC (accessed 18 October 2022).

IRENA (2022b), *NDCs and Renewable Energy Targets in 2021*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jan/IRENA_NDCs_RE_Targets_2022.pdf (accessed 20 October 2022).

IRENA (2022c), *World Energy Transitions Outlook: 1.5°C Pathway*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2022/Mar/World-Energy-Transitions-Outlook-2022

IRENA (2022d), *Smart Electrification with Renewables: Driving the Transformation of Energy Services*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2022/Feb/Smart-Electrification-with-Renewables

IRENA (2020a), *Scenarios for the Energy Transition: Global Experience and Best Practices*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2020/Sep/Scenarios-for-the-Energy-Transition-Global-experience-and-best-practices (accessed 25 June 2021).

IRENA (2020b), *Planning with Net-Zero Scenarios: Moving from Political Ambition to Country-Level Pathways*, International Renewable Energy Agency, Abu Dhabi, www.youtube.com/watch?v=sP-Fdx-KZTs&t=4469s (accessed 20 October 2022).

Levin, K. *et al.* (2018), *Long-Term Low Greenhouse Gas Emission Development Strategies: Approaches and Methodologies for Their Design*, www.wri.org/research/long-term-low-greenhouse-gas-emission-development-strategies-approaches-and-methodologies (accessed 4 November 2022).

Ministry of Ecological Transition, Italy (2020), *Integrated National Energy and Climate Plan*, LTES, Ministry of Ecological Transition, Ministry of Economic Development and Ministry for Transport, Italy, https://energy.ec.europa.eu/system/files/2020-02/it_final_necp_main_en_0.pdf.

Ministry of Energy, Chile (2021), *PELP 2023-2027*, LTES, Ministry of Energy, Chile, https://unfccc.int/sites/default/files/resource/CHL_LTS_2021.pdf.

Ministry of Energy, Chile (2020), *Carbono Neutralidad en el Sector Energia*, LTES, Ministry of Energy, Chile, https://energia.gob.cl/sites/default/files/pagina-basica/informe_resumen_cn_2019_v07.pdf.

Ministry of Energy, Kenya (2022), *Updated Least Cost Power Development Plan*, LTES, Ministry of Energy, Kenya.

Ministry of Energy and Mines, Dominican Republic (2022), *Plan Energético Nacional 2022-2036 (PEN)*, LTES, Comisión Nacional de Energía (CNE), Ministerio de Energía y Minas (MEM), Dominican Republic, www.cne.gob.do/documentos/plan-energetico-nacional-pen/.

Ministry of Environment, Cambodia (2021), *Long-term Strategy for Carbon Neutrality (LTS4CN)*, LT-LEDS, National Council for Sustainable Development, Ministry of Environment of Cambodia, Kingdom of Cambodia, https://unfccc.int/sites/default/files/resource/KHM_LTS_Dec2021.pdf.

Ministry of Environment, Czech Republic (2018), *Climate Protection Policy of the Czech Republic. Executive Summary 2017*, LT-LEDS, Ministry of Environment, Czech Republic, https://unfccc.int/files/na/application/pdf/cze_climate_protection_policy_summary.pdf.

Ministry of Environment, The Gambia (2022), *The Gambia's Long-Term Climate-Neutral Development Strategy 2050*, LTES, Ministry of Environment, Climate Change and Natural Resources, The Gambia.

Ministry for Environment and Forestry, Indonesia (2021), *Long-Term Strategy for Low Carbon and Climate Resilience 2050 (Indonesia LTS-LCCR 2050)*, LT-LEDS, Ministry for Environment and Forestry, Indonesia, https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf.

Ministry of Natural Resources and Environment, Thailand (2021), *Mid-Century, Long-Term Low Greenhouse Gas Emission Development Strategy*, LT-LEDS, Ministry of Natural Resources and Environment, Kingdom of Thailand, https://unfccc.int/sites/default/files/resource/Thailand_LTS1.pdf.

National Council of Energy, El Salvador (2020), *Estudio Prospectiva Energética 2020-2035*, LTES, Consejo Nacional de Energía, El Salvador.

National Energy Office, Marshall Islands (2018), *RMI Electricity Roadmap*, LTES, National Energy Office, Marshall Islands, https://unfccc.int/sites/default/files/NDC/2022-06/RMI%20Electricity%20Roadmap.pdf.

Net Zero Tracker (2022), *Net Zero Tracker*, Tracker, https://zerotracker.net/ (accessed 20 October 2022).

Riddle, M. E. *et al.* (2021), "Agent-based modeling of supply disruptions in the global rare earths market", *Resources, Conservation and Recycling*, Vol. 164, p. 105193, https://doi.org/10.1016/j.resconrec.2020.105193.

Takuma Watari *et al.* (2020), "Review of critical metal dynamics to 2050 for 48 elements", *Resources, Conservation and Recycling*, Vol. 155, p. 104669, Elsevier, https://doi.org/10.1016/j.resconrec.2019.104669.

UNFCCC (2022), *LT-LEDS Synthesis Report*, https://unfccc.int/lt-leds-synthesis-report (accessed 4 November 2022).

APPENDIX

Institutional survey

Survey for IRENA National Energy Transition Planning Dashboard

Instructions		
How do I complete the survey?	**Respondent information**	
Please use the cells in yellow to provide your responses. In the section on the right, please provide information about the respondent. The below survey contains three sections of survey questions. The first section refers to the country's recent official energy planning documents (see the question below for further details). The second segment refers to the modelling scope used to produce scenarios in the aforementioned planning document. The third segment refers to the most ambitious/desirable scenario (see below for the definition), its description, and its targets and constraints.	**Name of the respondent**	
	Affliation and position	
	Email address	
	Country	

If you have any questions, please send an email to ltes@irena.org.

<table>
<tr><th colspan="5">Survey</th></tr>
<tr><th></th><th></th><th>Planning document 1</th><th>Planning document 2 (optional if more than one)</th><th>Planning document 3 (optional if more than one)</th></tr>
<tr><td>Which energy planninig documents are relevant to this survey?</td><td>Document details</td><td></td><td></td><td></td></tr>
<tr><td rowspan="8">We ask the respondent to identify the energy planninig documents that are based on quantatative scenarios, produced or commissioned by an official govermnet body and used as part of regular official planning process. These can refer to any type of document (e.g. energy masterplans, integrated resource plans, national and energy climate plan), which have a time horizon of at least 15 years. When multiple pulblic administration offices produce different planning documents with differnt scopes (e.g., net-zero scenarios commissioned by climate authorites), please report all of them in separate columns (columns D and E).

In case “official energy planning documents/sceanarios” cannot be defined as such, we will leave it to the discretion of the respondent to identify those that are closest to “official planning documents/scenarios”.

If in doubt about which publications to report, please don’t hesitate to discuss with the LTES team.</td><td>Official planning document name
Please write the full name of your country’s official energy planning document</td><td></td><td></td><td></td></tr>
<tr><td>Published by
Please write the full name of the institution responsible for publishing the planning document.</td><td></td><td></td><td></td></tr>
<tr><td>Frequency of update</td><td></td><td></td><td></td></tr>
<tr><td>Publication link (please attach if not available online)</td><td></td><td></td><td></td></tr>
<tr><td>Objective of planning document
Please mention if this is regularly updated long-term planning document, a net-zero document, or any other type of publication. Please mention if this is part of a wider policy or target.</td><td></td><td></td><td></td></tr>
<tr><td>Was stakeholder consultation included in development of the document?
If yes, please provide a short description</td><td></td><td></td><td></td></tr>
<tr><td>Is this document aligehd with Nationally Determind Contributions (NDCs)?</td><td></td><td></td><td></td></tr>
<tr><td>Is this document used as LT-LEDS submission to the UNFCCC?</td><td></td><td></td><td></td></tr>
</table>

Survey				
		Planning document 1	**Planning document 2** (optional if more than one)	**Planning document 3** (optional if more than one)
	Planning document scope			
	Demand assessment *Has the current and future energy demand been assesed explicitly as part of this exercise?*			
	Energy system *Has the whole energy system been assessed?*			
	Power capacity expansion *Does the model simulate generation and transmission capacity investment?*			
	Closed or open economy model? *Does the analysis take into account the international or regional context (i.e. trade)?*			
What scenarios are being assessed? Which scenario/s should I use to complete this survey?	**Scenario details**			
Please identify the most desirable/ambitious scenario the scenario which best reflects coutry's vision towards the energy transition, and describe the scope of the scenario. If there are several scenarios with a similar level of ambition, please use addition columns to provide the information on these scenarios as well. If in doubt about which scenarios to report, please don't hesitate to discuss with the LTES team.	Modelling tools used *Please list all modelling tools/ software used to develop the scenarios in this publication. Add the name of the developer of the tool in parenthesis.*			
	Number of scenarios assessed			
	Most ambitious/desirable scenario name *Please state the name of the most ambitious scenario in terms of its GHG emissions in the planning document. (Refer to the instructions for explanation)*			

Survey				
		Planning document 1	**Planning document 2** (optional if more than one)	**Planning document 3** (optional if more than one)
What scenarios are being assessed? Which scenario/s should I use to complete this survey?	**Scenario details**			
Please identify the most desirable/ambitious scenario the scenario which best reflects coutry's vision towards the energy transition, and describe the scope of the scenario. If there are several scenarios with a similar level of ambition, please use addition columns to provide the information on these scenarios as well. If in doubt about which scenarios to report, please don't hesitate to discuss with the LTES team.	Description of the most ambitious/desirable scenario *Please describe the narrative/ storyline of the scenario, its objectives and targets, and any highlights/milestones (e.g. net-zero by 2040 or 100% renewables)*			
	If this scenario reaches net-zero CO_2, at which year does it reach it?			
	If this scenario reaches net-zero GHG (climate neutral), at which year does it reach it?			
	Is an emissions target included?			
	Emissions target description (if available)			
	Is a renewable energy target included?			
	Renewable target description (if available)			
	Other scenarios assessed *Please state scenario names and short descriptions*			

Technical survey

Survey for IRENA National Energy Transition Planning Dashboard

Fields in red = for your completion
Respondant information
[Name of the respondant]
[Affliation, and position]
[Email address]
[Country]

If you have any questions, please send an email to ltes@irena.org.

Instructions
(1) What scenarios are being assessed? Which scenario/s should I use to complete this survey?

Required: Official LTES
Please base the survey off of the long-term energy scenarios (LTES) produced or commissioned by an official government body as part of the regular official planning process and in the country's strategy documents. The respondant should fill in the survey based on what the scenarios in the plan/study collectively cover.

Such a document may or may not represent a "Net-Zero" scenario (see diagram to the right). If it does not, please see below.

If different from the above: Net-zero CO_2 or GHG scenario:
In some countries, a government body or commission may produce a dedicated net-zero scenario study, which is separate from the official LTES process. If that is the case, we request to provide the information on scenarios from that study seperately.

Document details
Required: Official planning document name ***Please write the full name of your country's official energy planning document***
If necessary: Separate net-zero document name ***Please write the full name of the document that contains a separate net-zero scenario***

(2) What is the survey structure?

The survey aims to assess the comprehensiveness of scenarios, in terms of elements that the LTES network considers key to the clean energy transition.

We mapped these elements in an illustrative presentation shown on the right ("energy transition scenario landscape"). It places the three technology pathways of electrification in the center (direct electrification, hydrogen based electrication, and E-fuel based electricfication) which require different types of transmission and distribution infrastructure. This is supplemented by other emission mitigation measures, *i.e.*, direct use of RE heat and bioenergy, energy efficiency and conservation, and LULUCF/CCUS/CDR.

The survey structure follows the landscape mapping components, including: (1) Electrification pathway infrastructure: Production (yellow); Transmission and distribution (orange); Storage (purple); End-use sector (dark blue); (2) non-electricity-based decarbonisation alternatives (light blue); (3) Key resource contraints (green); and (4) "Non-technical" scenario components (grey).

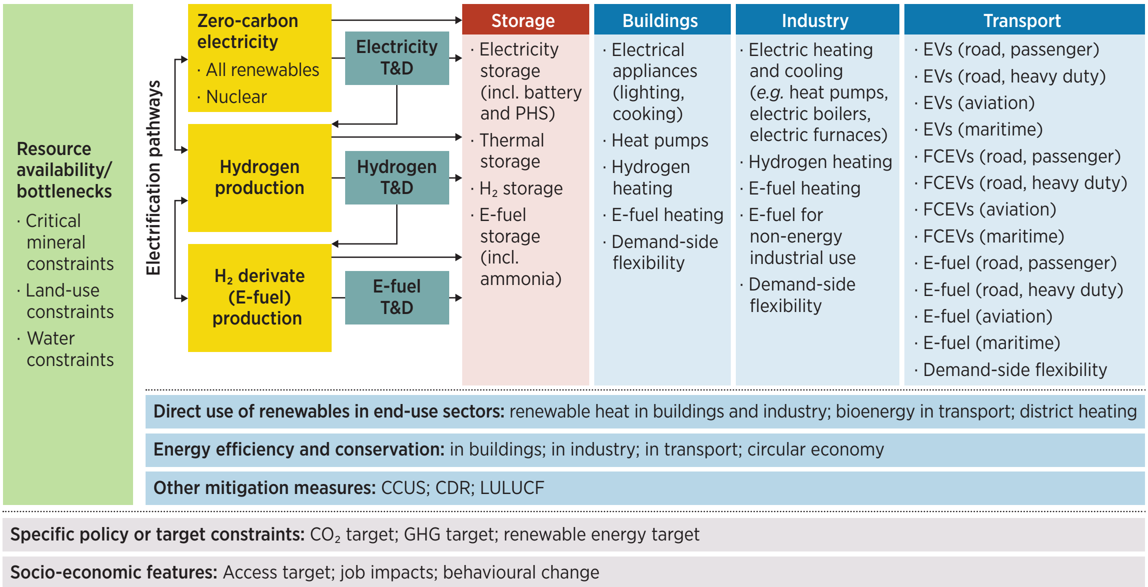
(3) How do I fill out the survey?

Below in the survey you will see the list of the elements. In the cells in red, please select how these elements are represented in your scenario. You are provided with four options:

- Quantitative: The component is explicitly included in the scenario and it is represented in a quantatative manner. For example, the scenario explicitly includes heat pumps in buildings as an option to be built, and there are specific quantitative inputs/outputs related to heat pumps in buildings.
- Qualitative: The component is represented in the scenario in a qualitative manner as a part of the overall narrative, but not as its own specific option with quantitative parameters. For example, the scenario may only represent the buildings sector broadly (*i.e.* only produce results at a higher level), in whch the presence of heat pumps are inplicitely assumed. In this case, we consider heat pumps to be qualitatively represented.
- Not included: The component is not included quantitatively or qualitatively in the modelling, inputs or results of the scenario.
- Not sure: You do not know which category above is appropriate - please include an explanation in the "Comment" field if this is the case.

Column A of the survey below has an explanation of what is being requested for each component. Please use the comment field for any clarifications or more specific information required.

Technical survey intro: Energy transition landscape



Survey

Please select how the components in column C are represented in the scenario/s - see instructions above for explanation of options

Optional if different from the LTES

		LTES document name:		**Net-zero document name:**	
		How is the element represented?	**Comments**	**How is the element represented?**	**Comments**
	Power production				
How is solar PV represented in the scenarios?	Solar PV				
How is onshore wind represented in the scenarios?	Onshore wind				
How is offshore wind represented in the scenarios?	Offshore wind				
How is concentrated solar power represented in the scenarios?	CSP				
How is hydropower represented in the scenarios?	Hydropower				
How is geothermal represented in the scenarios?	Geothermal				

Survey					
		How is the element represented?	**Comments**	**How is the element represented?**	**Comments**
	Power production				
How is ocean energy represented in the scenarios?	Ocean energy				
How is bioenergy represented in the scenarios?	Bioenergy				
How is nuclear represented in the scenarios?	Nuclear				
	Other production				
Hydrogen production = do the scenarios represent the process (including parameters like cost and operation) of converting electricity into hydrogen.	Hydrogen production				
Hydrogen derivative production (E-fuels) = do the scenarios represent the process (incl. parameters like cost and operation) of converting hydrogen into its derivative E-fuels.	Hydrogen derivative production (*i.e.* E-fuels)				
	Transmission and distribution				
Electricity T&D = do the scenarios represent the process (including parameters like cost and operation) of transmitting and distributing electricity.	Electricity T&D				
Hydrogen T&D = do the scenarios represent the process (including parameters like cost and operation) of transmitting and distributing hydrogen.	Hydrogen T&D				
E-fuel T&D = do the scenarios represent the process (including parameters like cost and operation) of transmitting and distributing hydrogen derviatives, aka E-fuels.	E-fuel T&D				

Survey					
		How is the element represented?	Comments	How is the element represented?	Comments
	Storage				
Electricity storage = do the scenarios represent the process (including parameters like cost and operation) of storing electricity (you may add details on the technology type in the comments, if necessary).	Electricity storage (incl. battery and PHS)				
Thermal storage = do the scenarios represent the process (including parameters like cost and operation) of storing heat (you may add details on the technology type in the comments, if necessary).	Thermal storage				
Hydrogen storage = do the scenarios represent the process (including parameters like cost and operation) of storing hydrogen (you may add details on the technology type in the comments, if necessary).	Hydrogen storage				
E-fuel storage = do the scenarios represent the process (including parameters like cost and operation) of storing E-fuels (you may add details on the technology type in the comments, if necessary).	E-fuel storage (hydrogen derivative incl. ammonia)				
	End use sectors - buildings				
Electric applicances = do the scenarios represent the deployment and use (including parameters like cost and operation) of electric applicances in buildings.	Electric appliances (stove, lighting)				

Survey					
		How is the element represented?	**Comments**	**How is the element represented?**	**Comments**
	End use sectors - buildings				
Heat pumps = do the scenarios represent the deployment and use (including parameters like cost and operation) of heat pumps in buildings.	Heat pumps				
Hydrogen heating = do the scenarios represent the deployment and use (including parameters like cost and operation) of hydrogen heating in buildings.	Hydrogen heating				
E-fuel heating = do the scenarios represent the deployment and use (including parameters like cost and operation) of E-fuel heating in buildings.	E-fuel heating				
Demand-side flexibility = do the scenarios represent the deployment and use (including parameters like cost and operation) of measures or technologies to increase demand flexibility in buildings, *e.g.* smart heating and cooling (you may add details in the comments, if necessary).	Demand-side flexibility				
	End use sectors - transport				
EVs (road, passenger) = do the scenarios represent the deployment and use (including parameters like cost and operation) of electric vehicles for road passenger transport.	Electric vehicles (road, passenger)				

Survey					
		How is the element represented?	Comments	How is the element represented?	Comments
	End use sectors - transport				
EVs (road, heavy duty) = do the scenarios represent the deployment and use (including parameters like cost and operation) of electric vehicles for heavy duty road use, such as freight.	Electric vehicles (road, heavy duty)				
EVs (aviation) = do the scenarios represent the deployment and use (including parameters like cost and operation) of electric vehicles for aviation.	Electric vehicles (aviation)				
EVs (maritime) = do the scenarios represent the deployment and use (including parameters like cost and operation) of electric vehicles for maritime transport of passengers or goods.	Electric vehicles (maritime)				
FCEVs (road, passenger) = do the scenarios represent the deployment and use (including parameters like cost and operation) of fuel cell electric vehicles for road passenger transport.	Fuel cell vehicles (road, passenger)				
FCEVs (road, heavy duty) = do the scenarios represent the deployment and use (including parameters like cost and operation) of fuel cell electric vehicles for heavy duty road use, such as freight.	Fuel cell vehicles (road, heavy duty)				
FCEVs (aviation) = do the scenarios represent the deployment and use (including parameters like cost and operation) of fuel cell electric vehicles for aviation.	Fuel cell vehicles (aviation)				

Survey					
		How is the element represented?	**Comments**	**How is the element represented?**	**Comments**
	End use sectors - transport				
FCEVs (maritime) = do the scenarios represent the deployment and use (including parameters like cost and operation) of fuel cell electric vehicles for maritime transport of passengers or goods.	Fuel cell vehicles (maritime)				
E-fuel (road, passenger) = do the scenarios represent the deployment and use (including parameters like cost and operation) of E-fuel-based vehicles for road passenger transport.	E-fuel vehicles (road, passenger)				
E-fuel (road, heavy duty) = do the scenarios represent the deployment and use (including parameters like cost and operation) of E-fuel-based vehicles for heavy duty road use, such as freight.	E-fuel vehicles (road, heavy duty)				
E-fuel (aviation) = do the scenarios represent the deployment and use (including parameters like cost and operation) of E-fuel-based vehicles for aviation.	E-fuel vehicles (aviation)				
E-fuel (maritime) = do the scenarios represent the deployment and use (including parameters like cost and operation) of E-fuel-based vehicles for maritime transport of passengers or goods.	E-fuel vehicles (maritime)				

Survey					
		How is the element represented?	Comments	How is the element represented?	Comments
	End use sectors - transport				
Demand-side flexibility = do the scenarios represent the deployment and use (including parameters like cost and operation) of measures or technologies to increase demand flexibility in transport, *e.g.* smart charging (you may add details in the comments, if necessary).	Demand-side flexibility				
	End use sectors - industry				
Electric heating & cooling = do the scenarios represent the deployment and use (including parameters like cost and operation) of electric heating and cooling technology in industry, such as heat pumps, electric boilers, and electric furnaces.	Electric heating & cooling				
Hydrogen heating = do the scenarios represent the deployment and use (including parameters like cost and operation) of hydrogen heating technology in industry.	Hydrogen heating				
E-fuel heating = do the scenarios represent the deployment and use (including parameters like cost and operation) of E-fuel heating technology in industry.	E-fuel heating				
Non-energy industrial use (E-fuel) = do the scenarios represent the deployment and use (including parameters like cost and operation) of E-fuels for non-energy use in industry, *e.g.* as feedstock.	Non-energy industrial use (E-fuel)				

Survey					
		How is the element represented?	**Comments**	**How is the element represented?**	**Comments**
	End use sectors - industry				
Demand-side flexibility = do the scenarios represent the deployment and use (including parameters like cost and operation) of measures or technologies to increase demand flexibility in industry (you may add details in the comments, if necessary).	Demand-side flexibility				
	Direct use of RE heat and bioenergy in end-uses				
RE heat in buildings = do the scenarios represent the deployment and use (including parameters like cost and operation) of renewable energy directly for heat in buildings, *e.g.* solar CSP.	In buildings - Renewable heat				
RE heat in industry = do the scenarios represent the deployment and use (including parameters like cost and operation) of renewable energy directly for heat in industry *e.g.* solar CSP.	In industry - Renewable heat				
Bioenergy in transport = do the scenarios represent the deployment and use (including parameters like cost and operation) of bioenergy-based technologies in transport.	In transport - Bioenergy				
District heating = do the scenarios represent the deployment and use (including parameters like cost and operation) of district heating.	District heating				

Survey					
		How is the element represented?	**Comments**	**How is the element represented?**	**Comments**
	Energy efficiency and conservation				
Efficiency and conservation (buildings) = do the scenarios represent the deployment and use (including parameters like cost and operation) of energy efficiency or reduction measures in buildings sector end-use technologies.	In buildings				
Efficiency and conservation (transport) = do the scenarios represent the deployment and use (including parameters like cost and operation) of energy efficiency or reduction measures in transport sector end-use technologies.	In transport				
Efficiency and conservation (industry) = do the scenarios represent the deployment and use (including parameters like cost and operation) of energy efficiency or reduction measures in industry sector end-use technologies.	In industry				
Circular economy = do the scenarios specifically represent circular economy approaches to reducing material throughput and waste (you may add details in the comments, if necessary).	Circular economy				
	Other mitigation measures				
CCUS = do the scenarios represent the deployment and use (including parameters like cost and operation) of processes in which CO_2 is captured and then used to produce a new product or stored in a product for a climate-relevant time horizon.	Carbon capture, utilisation, ans storage (CCUS)				

Survey

		How is the element represented?	Comments	How is the element represented?	Comments
	Other mitigation measures				
CDR = do the scenarios represent the deployment and use (including parameters like cost and operation) of anthropogenic enhancement of biological or geochemical sinks and/or direct air capture and storage.	Carbon dioxide reduction (CDR)				
LULUCF = do the scenarios represent emissions and removals of greenhouse gases resulting from direct human-induced land use such as settlements and commercial uses, land-use change, and forestry activities.	Land Use, Land-Use Change and Forestry (LULUCF)				
	Resource availability				
Critical minerals = do the scenarios represent constraints on the availability of potentially scarce materials necessary for the energy transition, such as cobalt, copper, nickel, lithium, and rare earth metals.	Critical mineral constraints				
Land-use = do the scenarios represent constraints on the availability of land required for the energy transition.	Land-use constraints				
Water = do the scenarios represent constraints on the availability of water required for the energy transition.	Water constraints				
	Policy or target constraints				
CO_2 target = do the scenarios contain a specific CO_2 target. If yes, please include a description of the target in the comments section, including type and year of target.	CO_2 target				

Survey					
		How is the element represented?	**Comments**	**How is the element represented?**	**Comments**
	Policy or target constraints				
GHG target = do the scenarios contain a specific GHG target. If yes, please include a description of the target in the comments section, including type and year of target.	GHG target				
Renewable energy target = do the scenarios contain a specific renewable energy target. If yes, please include a description of the target in the comments section, including type and year of target.	Renewable energy target				
	Socio-economic elements				
Access target = do the scenarios contain a specific energy access target. If yes, please include a description of the target in the comments section, including type and year of target.	Access target				
Job impacts = do the scenarios contain specific inputs and/ or outputs related to the job impacts of the energy transition.	Job impacts				
Health impacts = do the scenarios contain specific inputs and/ or outputs related to the health impacts of the energy transition.	Health impacts				
Behavioural change = do the scenarios contain specific inputs and/or outputs to reflect the effect of behavioural change - *i.e.* changes in societal acceptance, adoption or use of goods, services, and/or infrastructures.	Behavioural change				

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