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*Review*

# Best Practice in Government Use and Development of Long-Term Energy Transition Scenarios

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**Abstract:** Long-term energy scenarios (LTES) have been serving as an important planning tool by a wide range of institutions. This article focuses on how LTES have been used (and also devised in some cases) in the government sector, and specifically how the new challenges and opportunities brought by the aspiration for the clean energy transition change the way that governments use LTES. The information tends to remain tacit, and a gap exists in understanding the way to enhance LTES use and development at the government level. To address this gap, we draw on the experience from national institutions that are leading the improvement in official energy scenario planning to articulate a set of overarching best practices to (i) strengthen LTES development, (ii) effectively use LTES for strategic energy planning and (iii) enhance institutional capacity for LTES-based energy planning, all in the context of new challenges associated with the clean energy transition. We present implementation experience collected through the International Renewable Agency's LTES Network activities to exemplify these best practices. We highlight that in the context of the broad and complex challenges of a clean energy transition driven by ambitious climate targets, the LTES-based energy planning methodologies need to evolve, reflecting the changing landscapes, and that more effective and extensive use of LTES in government needs to be further encouraged.

**Keywords:** long-term energy scenarios; energy planning; energy modelling; clean energy transition; climate scenarios

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## 1. Introduction

The clean energy transition poses a unique challenge, particularly to energy planners [1–3], who must deal with envisioning the changes of the energy system in a context of uncertainty and rapid change. The growing deployment of low-cost renewables, the need for a more integrated, innovative and flexible power grid and the impacts of demand and consumer behaviour through end use electrification are some of the key transition features that energy planners must include in any long-term analysis. The energy transition will also be supported by advanced policy frameworks and market mechanisms, which will generate new business models and fundamentally transform the status quo [4–7]. Expanding pressures to align the economy to low emission carbon pledges and the climate objectives of the Paris Agreement necessitate a more aggressive strategy than previous approaches that sought to stabilise or halve emissions [8–11]. Policy and decision making must have a strategic, forward-looking approach that continually embeds new evolutions and uncertainties in policy, markets and technology.

Long-term energy scenarios (LTES) have been traditionally the building block of national energy planning, supporting the development of national energy plans, national energy outlooks, electricity generation and transmission capacity expansion plans and energy demand analysis [12–27]. LTES can help government planners to prepare for the long-term policy interventions, identify the short-term challenges and opportunities and inform recommendations on where to direct domestic and foreign investment [28,29]. Most recently, LTES use has broadened to the climate community, and they are being used for designing nationally determined contributions (NDC) [30] and, most importantly, long-term low emission development strategies (LT-LEDS) [31], which should be submitted by all signatory countries of the Paris Agreement. While the global and regional LTES also inform national policy debate, the focus of this article is on national LTES, built by or built for governments for their planning purposes, unless otherwise specified.

LTES are mostly developed with energy modelling tools [32–34], which help to develop a mathematical representation of a part or the totality of the energy system. Models allow representing the complex interdependencies within an energy system and its linkages to broader societal and environmental factors and assess the short and long-term impacts of choices of technological pathways and policy choices. However, given the substantial future uncertainties caused by an accelerated energy transition [35–38], using deterministic quantitative models can often produce misleading conclusions. For example, retrospective analysis of the projected solar photovoltaic and wind energy installed capacity has shown a consistent underestimation when compared to current trends [39–41]. It also reflects the fact that as scenario analysis becomes more influential, society may dynamically respond to messages portrayed by such analysis. Even with better modelling approaches, enhanced computational power and refinement of input data, it is impossible to validate long-term scenario results [42–44]. In this sense, model-based scenario analysis benefits have focused on assessing a wide range of pathways and gaining insights from them, rather than aiming to narrow the ranges and to produce "accurate" predictions. The notion of accurate prediction could be misleading given the inherent uncertainties of technology progress in the long run and the dynamic nature of policy interventions.

The energy scenario modelling community, academia and research communities have demonstrated various improvements of modelling approaches, and these are well documented (e.g., [45–49]). To our knowledge, however, the government's application of national-level LTES and the best practices and experience in using them to guide the clean energy transition remain as gaps. Although we recognise that government practices are highly context specific, the objective rules on how governments develop and use LTES can be drawn from learning from others. We therefore see that it is critical to synthesise the tacit knowledge underpinning effective LTES analysis in the government. This paper aims at formalising best practices in using and developing LTES in the government in the context of the clean energy transition. It seeks to complement the recent literature that is studying energy transition scenarios in the context of sustainability [50], geopolitics [51], societal processes [52], modelling methods [53] and economic impacts [54] by engaging with those who rely on scenario-based results to help navigate the energy transition—i.e., government energy planners. We address three currently unmet objectives in the literature: i) to showcase examples of successful application of LTES in the government, ii) to establish scenario best practices to address the energy transition through community-wide efforts and iii) to inform energy planners on effective use scenario-based analysis. We draw on the collective experience of national energy institutions in different countries worldwide that are members of the International Renewable Agency's (IRENA) Long-Term Energy Scenarios Network (LTES Network) (IRENA LTES Network webpage: https://irena.org/energytransition/Energy-Transition-Scenarios-Network (accessed on 23 January 2022)) [55–57], thus providing a global and comprehensive view on how governments are adapting their scenario practices to the requirements of the energy transition.

We categorise a set of best practices into three critical pillars for national LTES, namely (i) strengthening scenario development, (ii) improving scenario use and (iii) identifying capacity-building approaches. [53] While we focus on LTES in the government, the recommendations can be applied in other sectors using scenarios for decision-making.

## 2. Mental Model of IRENA's LTES Network

The objective of IRENA's LTES network is to advocate the effective use of LTES as a tool for planning to accelerate the energy transition [57]. The process for developing LTES and using them is encompassed within the chain of the energy policy making process (Figure 1), which is also a part of the overarching energy planning practice in the government. The LTES typically (though not always) uses results from energy modelling as inputs, involving energy modellers and analysts to quantify policy implications, draw outlooks and identify uncertainties. The policy making process involves decision-makers who rely on scenario insights to design national planning documents, long-term energy policy and, more recently, climate targets. In contrast, qualitative scenario characteristics—such as future storylines and narratives—are shaped via stakeholder and expert elicitation at different stages. We note that the LTES use and development process, as seen in Figure 1, may also involve feedback loops among the stages.

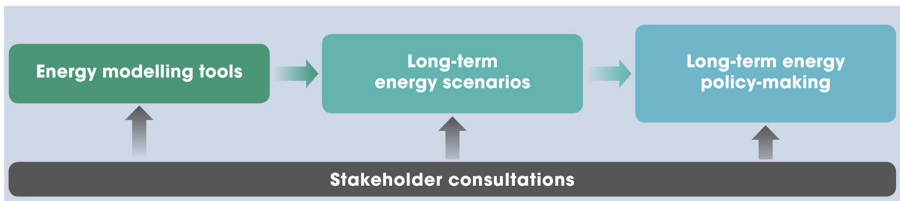


**Figure 1.** The mental model of IRENA's Long-Term Energy Scenarios network [57].

Three focus areas with respective focus questions were defined to systematically organise the information stemming from the LTES network's activities (Table 1). The collection of national experience in LTES and energy planning processes worldwide is country-specific and has touched upon a broad range of topics. However, we have found common features of good practice that we present in this paper. In strengthening scenario development, the focus has been on the definition of modelling scopes that capture the features of the energy transition. On improving the use of scenarios, the focus has been on strategic use of long-term energy scenarios for long-term policy making. On identifying institutional capacity, the focus has been on distilling best practices to source adequate scenario development abilities and human resources within government institutions.

**Table 1.** Focus areas of IRENA's LTES network and focus questions.

| Focus Area | Focus Question |
|---|---|
| 1. Strengthening scenario development | How to develop scenarios to better capture potentially transformational changes? |
| 2. Improving scenario use | How to use scenarios for better strategic decision-making by governments and investors? |
| 3. Identifying institutional capacity | How to better enhance institutional capacity for scenario planning? |

## 3. Best Practices for LTES in the Government

A set of best practices should drive LTES development and use to guide the energy transition. The best practices presented here are inspired by the discussions held with scenario experts who participated in IRENA's LTES network activities.

I. Robust development of LTES
   a. Establish a strong governance structure: broad participation of stakeholders and stronger coordination across different government institutions are needed
   b. Expand the boundaries of scenarios: emerging technologies, business models and disruptive innovations need to be better accounted for in LTES

II. Effective use of LTES

   a. Define the purpose of LTES: clarifying the purpose of LTES is needed as they can be used in different purposes in different contexts, leading to misinterpretation of the results.
   b. Communicate transparently and effectively: Innovative communication methods can be deployed to transparently share assumptions and results of LTES with stakeholders.

III. Institutional ownership of LTES capacity
   a. Develop the appropriate scenario planning capacity: different national circumstances lead to a unique institutional ownership model of LTES capacity, and the right balance of in-house government skills and support from third-party organisations can be identified.

In the following sections, we elaborate more on each best practice and provide examples of how countries implement these best practices. Where appropriate, we layout critical challenges that must be met.

## 4. Robust Development of LTES

### *4.1. Establishing a Strong Governance Structure*

The process of developing LTES differs throughout regions and contexts. Some governments have established advanced legal frameworks to outline LTES steps, stakeholders and the frequency of scenarios exercises [17,58,59], while others have less stringent guidelines or none at all, implying a more ad hoc approach. The clean energy transition necessitates better coordination and expansive governance of LTES development than before. For example, with distributed energy resources and smart grid technologies, the traditionally passive electricity consumers will be more active players of the energy system, i.e., prosumers, which will potentially influence and be influenced by LTES [60,61]. The massive electrification of end-use sectors with green electricity and the unique spatial and temporal characteristics of variable renewables require better coordination among institutions to operate the power system and to develop scenarios. Cities and regions are becoming part of the scenario process, whereas in the past scenario, planning was a more centralized top-down matter [62,63]. In addition, the link of the energy transition to climate policy requires better coordination amongst different institutional jurisdictions, e.g., energy scenarios developed by ministries of energy versus climate scenarios developed by ministries of environment catering to international climate pledges [64].

This best practice delves into two critical aspects to improve scenario development governance structures—(i) participatory processes; and (ii) coordination between entities.

#### 4.1.1. Participatory Processes

Participatory processes help to increase the legitimacy, acceptance and utility of LTES. Inviting various stakeholders to brainstorm on a possible range of scenarios is central to mapping expectations and creating a mutual vision of the future, which is crucial to discover perspectives that do not include the inherent governmental bias. An additional benefit from participatory processes is that it facilitates guaranteeing a just and inclusive energy transition. Impressive experience of successful participatory processes reaching out to hundreds of stakeholders to develop LTES has been found in Colombia to inform the National Energy Plan 2020–2050 [65] (Figure 2), Denmark to inform the Energy and Climate Outlook 2030 [24], Brazil to develop the National Energy Plan 2050 [12,13], the United Kingdom to inform National Grid's Future Energy Scenarios 2050 study [66], Chile to support its long-term energy and transmission planning governance [17] and in South Africa to update the assumptions of the Integrated Resource Plan 2019 [20].

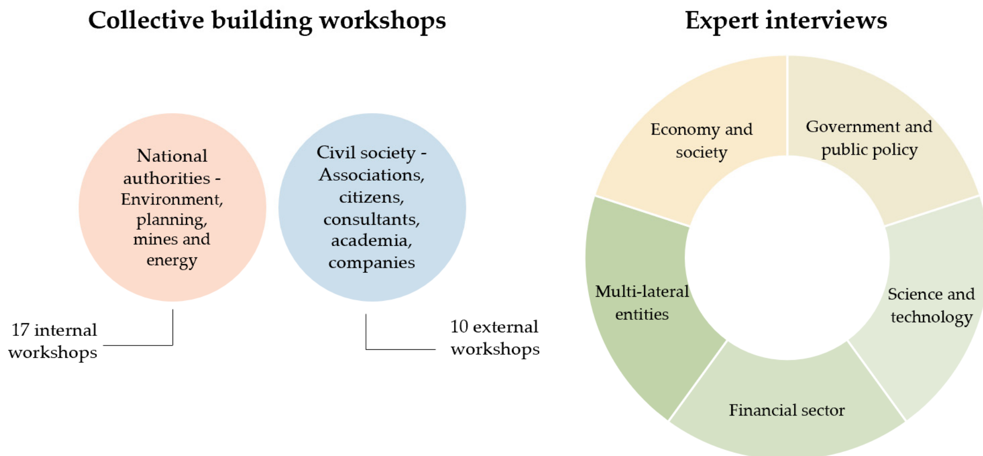


**Figure 2.** Colombia's scenario development participatory workshops for the national energy plan 2020–2050 carried out by Energy and Mining Planning Unit [67].

### 4.1.2. Coordination among LTES Entities

Stages of scenario development often involve a range of different institutions, and these may have specific methodologies according to their specific objectives and conditions. Developing national LTES in isolation (i.e., only by one institution) risks misinterpretation and misalignment amongst entities. Therefore, coordination among institutions can help to derive comparable and meaningful conclusions by, for example, approaching the same LTES question from different institutional perspectives. We identify three levels of coordination to improve LTES development particularly relevant to the energy transition. The first level of coordination is required between the institutions developing top-down official LTES (central government and ministries) and institutions conducting bottom-up technical studies for different power system segments. For example, the clean energy transition may demand a greater share of variable renewable energy (VRE) in a power system, which necessitates a range of energy planning models to be deployed in a coordinated manner (Figure 3).

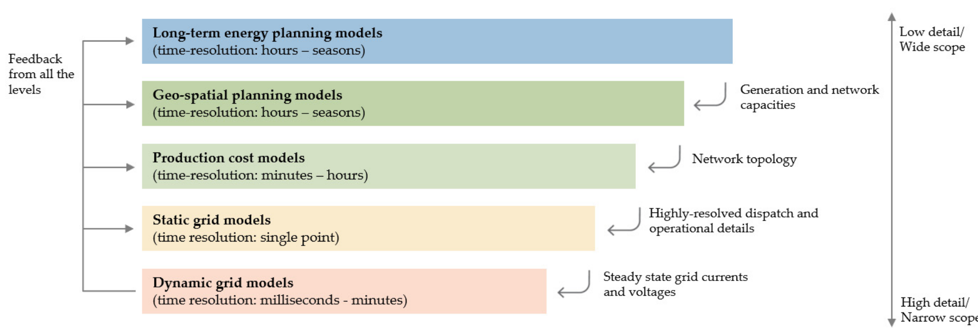


**Figure 3.** Tools with different scopes and their feedback loops for energy system scenario planning [34].

The second level of coordination is inter-institutional, between different sectors developing scenarios. In the context of the energy transition, this is namely between the climate community in charge of establishing climate targets and the energy planners who traditionally possess more knowledge of energy models and scenarios. National LTES must be aligned with climate target frameworks, such as Nationally Determined Contributions (NDC) [68]. In some instances, NDCs have shown to be more ambitious than LTES developed independently by energy ministries of agencies, or vice versa, which can be contradictory [69].

The third level of LTES coordination is between central and federal governments and between regional and national governing bodies. Here, the availability of local energy resources comes into play and complicates scenario governance. For example, an ambitious regional energy transition scenario may collide with a more conservative national-level scenario. LTES could be employed to study regional diversities and provide granularity to national level exercises, and beyond that to cater to regional planning needs and resource governance [70–73].

Good experience in coordination of LTES planning can be found in the United Arab Emirates National Energy Strategy 2050 development process, including all communities and local governments [74]; Canada's coordination among federal government organisations involved in data and modelling of LTES through the Federal Energy Information Framework, which aids the production of Canada's Energy Futures report (Figure 4) [75]; Costa Rica's 2050 Decarbonisation Plan, including energy and climate LTES [58]; and in the coordination between the European Network of Transmission System Operators for electricity (ENTSO-E) and gas (ENTSOG) to develop a common scenarios report by 2040 [76].

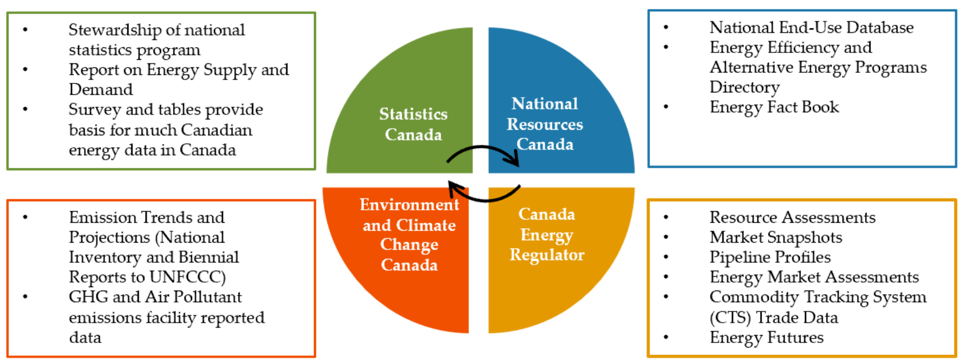


**Figure 4.** Canada's Federal Energy Information Framework [77].

### *4.2. Expanding the Boundaries of Scenarios*

Quantitative LTES, formulated by modelling tools, reflect the underlying model structure and its scope. To sufficiently reflect the complexity of the energy transition, it is necessary for emerging technologies, business models and disruptive innovations to be better addressed [78,79]. As end-users and end-use technologies increasingly change their roles in the energy system from passive to active, the distinction between supply and demand in the traditional sense is harder to draw [80–82]. However, characterising such disruptive innovations and radical societal changes in scenarios continues to pose a challenge and is at the forefront of energy modelling and consumer behaviour research [83–85]. How and when these innovations will be wholly developed and actively utilised can hardly be determined at the present. Thus, LTES are a valuable tool to explore the consequences of disruptive technologies and ambitious policy choices. Expanding the boundaries of scenarios delves into two essential aspects for national-level LTES—(i) developing LTES showcasing a just energy transition; and (ii) considering innovation in the energy sector.

#### 4.2.1. Scenarios for a Just Energy Transition

The profound socioeconomic transformation that accompanies the energy transition and a low carbon economy raises questions from policymakers concerning the impacts on economic growth, employment, welfare and living conditions [50,51,86,87]. The clean energy transition will unveil "winners" that grasp the opportunities and "losers" that reap the risks; thus, policymakers are interested in pinpointing these groups to ensure adherence to the principle of equity [88]. The COVID-19 pandemic generated renewed attention to sustainable development pathways that can enable a green recovery. Integration of social considerations into scenario analysis is needed to enable policymakers to assess the impacts and timelines of a just transition [89,90]. We also recognise that the transition can be ill used for purposes of green washing [91] and to promote political agendas [92], and thus scenarios can be used to fact check pledges and to establish credible transition plans and targets that will reduce the misuse of transition narratives.

In Germany, a government-appointed commission advised a complete and gradual elimination of coal by 2038 [93,94]. In January 2019, following an extensive consultation procedure, a phase-out plan was presented to offer a €40 billion economic package to affected coal regions, including alternative industry investment projects and state aid for coal workers [68]. In Finland, the VTT Technical Research Centre of Finland Ltd. (VTT) developed a modelling framework to analyse the impacts of the 2030 policies in the country's national economy, energy economy, natural resources, emissions and health (see Figure 5). The European Commission's scenario study, A Clean Planet for all, showcased scenarios with a time horizon of 2050 that considered the interplay between energy, the economy, land use and agriculture and non-$CO_2$ GHG and air pollution [95] (see Figure 6).

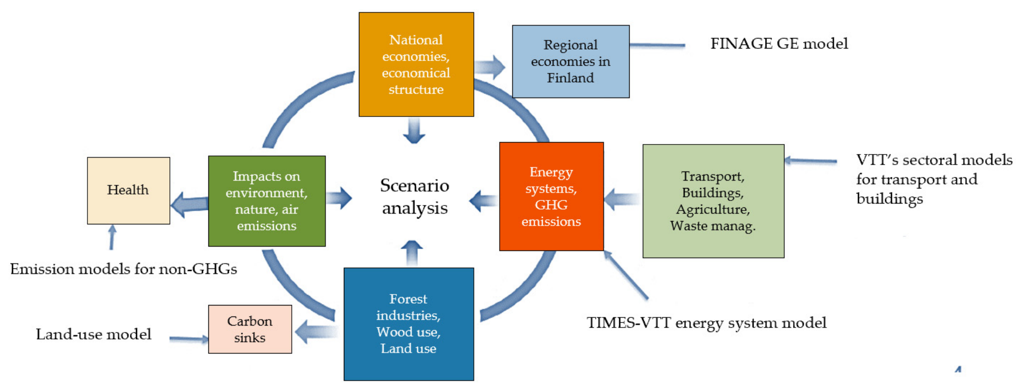


**Figure 5.** Finland's scenario modelling framework to study the impact of policies.

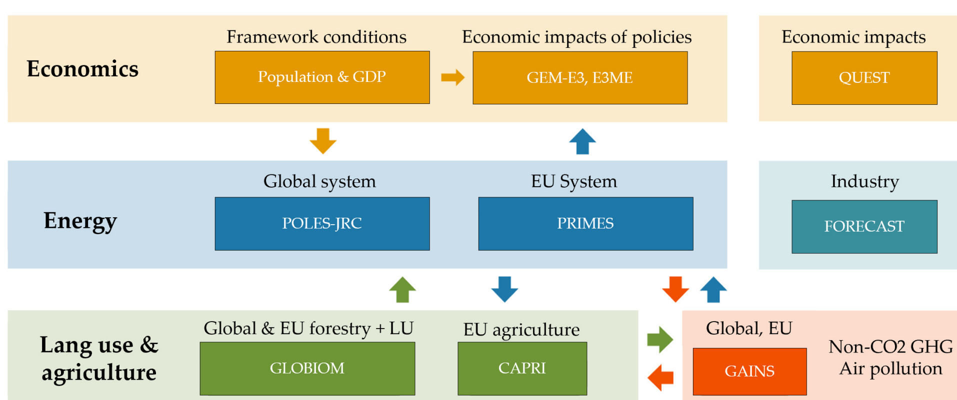


**Figure 6.** The European Commission modelling suite for integrated modelling of the economy, energy, land use and agriculture and air pollution [96].

4.2.2. Accounting for Innovation in the Energy Sector

Innovation in decentralisation, digitalisation and electrification are crucial components of the energy transition and need to be better accounted for in LTES. For example, amplifying auto-consumption from rooftop solar PV systems through the use of residential battery storage and electric vehicles (EVs) was not prominently considered by model designers 20–30 years ago [97–99]. Hydrogen, a key energy carrier to decarbonise energy-intensive industries, and how it may co-evolve with renewable electricity infrastructure, continues to be highly unaccounted-for in current techno-economic modelling [100–102]. Current scenarios also probably underestimate the growth sector coupling (VRE in transport, buildings and industry) [103–106]. IRENA has identified a set of 31 such innovations within four main categories relevant to the upscaling of variable renewable energy and which are relevant to consider expanding the boundaries of LTES for the transition (see Table 2).

**Table 2.** The landscape of innovations to integrate variable renewable energy.

| Enabling Technologies | Business Models | Market Design | System Operation |
|---|---|---|---|
| 1. Utility-scale batteries<br>2. Behind-the-meter batteries<br>3. EV smart charging<br>4. Renewable power-to-heat<br>5. Renewable power-to-hydrogen<br>6. IoT<br>7. AI and big data<br>8. Blockchain<br>9. Renewable mini-grids<br>10. Supergrids<br>11. Flexibility in conventional power plants | 12. Aggregators<br>13. P2P electricity trading<br>14. Energy-as-a-service<br>15. Community-ownership models<br>16. Pay-as-you-go models | 17. Increasing time granularity in electricity markets<br>18. Increasing space granularity in electricity markets<br>19. Innovative ancillary services<br>20. Re-designing capacity markets<br>21. Regional markets<br>22. Time-of-use tariffs<br>23. Market integration of distributed energy resources<br>24. Net billing schemes | 25. Future role of distribution system operators<br>26. Co-operation between transmission and distribution system operators<br>27. Advanced forecasting of variable renewable power generation<br>28. Innovative operation of pumped hydropower storage<br>29. Virtual power lines<br>30. Dynamic line rating |

The Japanese 5th Strategic Energy Plan 2050 [107] recognises the uncertainty of technological innovation and the ambiguity with regards to changes in conditions. To tackle the issue, it develops multiple-track scenarios that pursue all options, including renewable energy, hydrogen, carbon capture and storage and nuclear power. The Italian Integrated Energy and Climate Plan [108] considers a dimension of research and innovation action through the framework of scenario-building. It focuses on two modelling pillars: the first is concerned with power grids, integration of renewables, auto-production, storage, community energy and aggregators; and the second pillar focuses on facilitating EV adoption. In the United States of America, the National Renewable Energy Lab (NREL) explored targets, factors and innovation that affect electricity sector pathway decisions by 2050 [109].

## 5. Effective Use of LTES

### *5.1. Clarifying the Purpose of Scenario-Building*

LTES are contextually-dependent, employed for various objectives, and can be used differently depending on the necessary targets. It is crucial to clarify such distinctions to avoid misinterpreting scenario insights. While the inherent objective of scenario development is to offer a snapshot of the energy system of the future, the way that scenarios can be used and applied can vary. For example, scenarios are often developed as a part of the governments' infrastructure planning, such as transmission and capacity expansion investment planning [66,110]. Scenarios are also developed to explore radical transformations and ambitious climate targets [111,112], often as a part of a scientific exercise. Private companies also use scenarios more in the context of market forecasting. Clarifying the purpose of these scenarios can allow policymakers to use their insights correctly and compare them appropriately [113]. We have identified several (contrasting) use-cases of energy scenarios in the context of national energy planning. Figure 7 showcases the three polar distinctions made. However, it is essential to know that those are not considered binary choices but spectra in which the uses of national energy transition scenarios can be defined. The following subsections will elaborate on these distinctions.

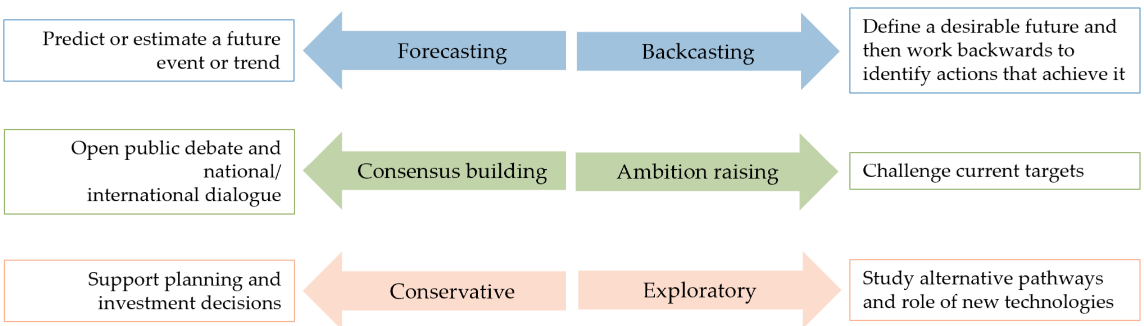


**Figure 7.** Categorisations of use-cases of LTES [57].

5.1.1. Forecasting and Backcasting

A forecasting-based scenario aims to predict future trends or events, inquiring, "what will happen, given certain decisions and policies?" Strict applications of forecasts are seldom in long-term energy planning (20–30+ years), as the distant horizon make predictions harder to make.

A backcasting-based scenario aims to provide backward pathways from a particular objective or target, in the process determining the policies needed to support this pathway, essentially asking the question, "how can this certain future be achieved?" These scenarios are best suited to study implications of decisions and cost-effective methods to reach national and global targets.

Government scenario developers have been shown to use a combination of backcasting and forecasting methods to produce scenarios. In China, the China National Renewable Energy Centre (CNREC) utilises backcasting scenario analyses to assess policy measures to reach the country's ambitious 2-degree targets by mid-century, as depicted in the 13th five-year plan [114], which is presented in the Annual Renewable Energy Outlook [115,116]. The backcasting is complemented by a forecasting method that reflects current stated short-term policies to ascertain further policy requirements to realize the clean energy transition.

5.1.2. Building Consensus and Raising Ambition

Long-term energy scenarios also act as a tool to initiate discourse and develop consensus on different visions of the future. For example, the Netherlands Environmental Assessment Agency (PBL) develops scenarios to support consensus-building among a wide set of stakeholders (at the national, provincial and municipal levels of governance) to implement climate legislation. PBL developed a model to represent decision-makers with different cost considerations and time horizons to simplify the exploration of options to achieve the clean energy transition [117]. However, a pitfall of developing scenarios with the aim of building consensus is that compromise amongst a diverse range of stakeholders could lead to half-baked or unambitious targets. On the other hand, normative scenarios are used to raise ambition to challenge current targets and stated policies and provide more ambitious pathways to inform national energy planning in line with global climate targets. Based on its REmap analysis and in collaboration with the European Commission, IRENA performed scenario analyses that found that the EU could supply half of its electricity from renewable energy by 2030. This research contributed to the European Council's decision to adopt a more ambitious target of 32% renewable-based energy by 2030. On the national level, other examples of ambition-raising scenario use have been found. In Ireland, projects developed by the International Energy Agency (IEA) Energy Technology Systems Assistance Programme (ETSAP) in co-operation with the University College Cork (UCC) led to developing more ambitious targets being legislated in the 2015 Climate Action and Low Carbon Development Act.

#### 5.1.3. Conservative and Exploratory Scenarios

Conservative scenarios are considered "plausible", which generally contain less ambitious targets, less drastic measures and lower-cost investment options. In contrast, exploratory scenarios push the boundary of opportunities for new and potential technologies, in effect preventing persistent business-as-usual conclusions, showcasing opportunities and potential disruptions, as well as identifying risks for the energy transition. We observed that most government institutions and power system operators are naturally conservative in developing scenarios. For instance, the National Grid—the UK's power system operator—publishes the Future Energy Scenarios report, which develops and identifies a range of conservative scenarios to inform policy and investment decisions [66]. It also acts as a reference point for other scenarios and academic studies. Another example is Ecuador's 10-year electricity master plan, which provides normative scenarios for generation and transmission capacity expansion [118]. Academia, research centres, and non-governmental organisations tend to take a position on the exploratory end of this spectrum [119]. Examples include the "100% renewable energy for Australia" report produced by the Institute of Sustainable Futures (ISF) at the University of Technology Sydney [112], the national deep decarbonization scenarios that the Institute for Sustainable Development and International Relations (IDDRI) carried out for six countries in Latin America [120], the study on climate neutrality for Japan published by Japan's Renewable Energy Institute (REI) and Agora Energiewende [121] and the report from the Indonesian Institute for Essential Services Reform (IESR) [122]. Such studies can help stimulate public debate and challenge government planners to push the assumptions beyond conservative limits.

### *5.2. Transparent and Effective Communication*

Scenarios can most often be used as an effective tool for communication that deciphers the complexities of the energy transition, transforming them into comprehensible and consistent messages. We identified that effectively communicating scenario results ensures the quality and trust of scenarios. Effective communication also includes transparency and accessibility to the underlying data used in models. For the purposes of this paper, communication involves all manners of transmitting information about the scenarios to the public, including publications [24,115,123], news briefs [74,124,125], web-platforms [15,126–129] and events [130–132].

#### 5.2.1. Effective Communication Tools

Communication facilitates the participatory process of developing scenarios, engages a broader set of non-energy stakeholders, and produces straightforward messaging that non-experts can understand. One such method of communicating scenarios is through web-based scenario visualization platforms and calculators. The UK's Department for Business, Energy and Industrial Strategy (BEIS) developed the Mackay Carbon Calculator. This online tool calculates the energy mix and resulting emissions based on various levels of ambition for different sectors with the horizon year of 2100. It provides the public with experience in scenario analysis and pathways and likewise provides BEIS with insights on the public's views [133]. Another such example of an online tool is Exploring

Canada's Energy Future, developed by Canada's Energy Regulator (CER), which is a web-based interactive tool based on the CER's Energy Futures report. The platform allows users to navigate by region, sector and type of scenario (demand or power) [75,126]. Innovative methods of communicating directly with policymakers were also showcased among LTES Network members. For example, the Ministry of Energy and Industry of the United Arab Emirates (UAE) created the game "Future Lab" in the context of its Energy Strategy for 2050 [74]. Future Lab allowed senior government officials to test each scenario's systemic opportunities and consequences to learn about the complexities of the future energy system. This was done by providing the officials with experiential insights, with sonic and visual effects simulating future environments, along with other insights including "smelling the burning air of the future" in a fossil-fuel heavy long-term scenario.

#### 5.2.2. Transparent and Publicly Available Information

Transparency of input data, methodology and model assumptions is necessary, as it allows scenarios to be carefully inspected by different stakeholders and allows policymakers to deduce which assumptions and narratives drive certain results. LTES discussions highlighted calls from various stakeholders (government and civil society organisations) for a clear explanation of key model input data, constraints, parameters and scenario outputs in order to avoid potential "black box" scenario approaches. This includes technology cost data, as a majority of scenario developers utilise technology cost projections for the medium and long-term, which can be subject to conservative approaches despite past trends having more drastic rates of change in costs. Availability of such data in a transparent manner is vital to develop trustworthy scenarios that feature input from a diverse set of participants, and to allow feedback and criticism from various experts and stakeholders. Examples of good practices exist across different LTES institutions. In Italy, the National Statistical System, which comprises a broad coalition of private and public bodies, publishes annual reports that contain official statistics used in the country's scenario publications, such as the Integrated National and Climate Plan (INECP) [108]. In Denmark, the Danish Energy Agency issues the Energy Cost and Technology catalogues, which make widely-available yearly updates on costs and technology efficiency, which are used as a reference point for scenario building [134]. In the United States, the National Renewable Energy Laboratory (NREL) publishes the Annual Technology Baseline report, which features current and forecasted cost and data for various technologies for use in the energy sector [135]. In Chile, the Ministry of Energy publishes its five-year Long-term Energy Planning process, including all details about committee formation, methodologies, assumptions and deadlines, as well as annual background reports on data used [17]. These methods, amongst others, create transparency and increase data legitimacy, which builds trust in both the scenario building and policy making processes for the country, and ensures more reliable research on future energy pathways.

## 6. Institutional Ownership of LTES Capacity

### *6.1. Building the Correct Type of LTES Capacity in Government*

From the government's perspective, LTES development (modelling) capacity can be either insourced or outsourced. Some governments build and maintain in-house modelling capacities within their energy ministries, energy agencies or other government-dependent institutions. Governments can also outsource scenario development to research, technical institutions or consultancies. There is also a middle-of-the-road option where government jointly develops modelling capacity with independent energy agencies or technical institutions. Figure 8 presents a conceptualization of where scenario building capacity can be allocated from the government's perspective. Insourcing or outsourcing are not mutually exclusive, and it is not that one is correct and the other is wrong. Still, we argue that each has distinct advantages and challenges that have been identified in countries that have successfully implemented them (see Table 3).

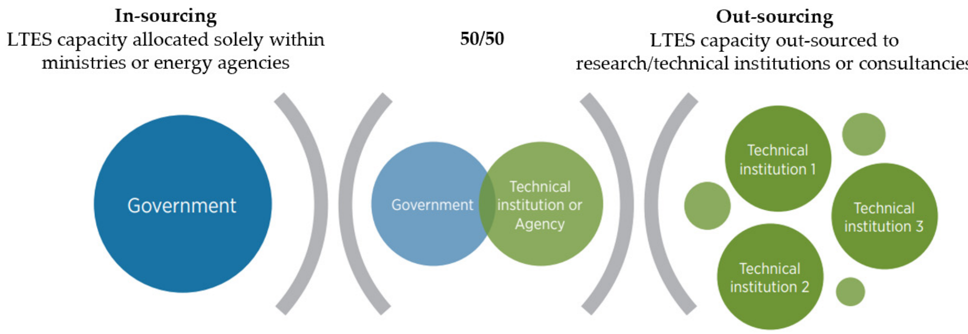


**Figure 8.** Allocation of LTES development capacity from the government's perspective.

**Table 3.** Keys for success and advantages and challenges of insourcing and outsourcing LTES development capacity from the government's perspective.

| Issue | Insourcing | Outsourcing |
|---|---|---|
| Allocation of capacity | Ministries or energy agencies. | Independent technical institutions or consultancies. |
| Government involvement | Allows for closer and more constant interaction with policymakers. | Can result in intermittent and shorter interactions with policymakers. |
| Scenario diversity | Tends to have a limited number of scenarios, usually reflecting less exploratory viewpoints. | Tends to cover a wider range of scenarios, reflecting the client's vision and agenda. |
| Quality of results | Relies on government technical capacity and access to tools and data. | Allows procurement from different high-end commercial tools tailored for purpose. |
| Response rate | Quick response to pressing government policy needs, subject to the capacity of the team. | May take time to procure scenarios but allows a different execution timing as required by government specifications. |
| Transparency | Ensures full transparency of inputs and outputs through closer interaction with in-house modelling team. | Tends to be black-box, and proprietary licences may potentially limit full access to the tools. |
| Cost | Possibly less costly but requires significant efforts to build modelling capacity. | Tends to be expensive to hire commercial consultancy firms. |
| Keys to success | Quality assurance (e.g., engaging with academia).<br>Team or agency devoted to modelling and scenario development.<br>Establishing an institutional process for systematic updates of LTES. | Absorptive capacity within a government to comprehend modelling outcomes.<br>Full disclosure of scenario data and modelling methodology;<br>Access to enough high-quality research institutions. |

6.1.1. Insourcing Scenario Development Capacity

Governments that have succeeded in institutionalising modelling capacity have a dedicated modelling and scenario team, an institutional process for regular updates of LTES, regular engagement with external stakeholders to establish quality assurance, continuous training activities and effective presentation of LTES benefits for decision-making. A key advantage of insourcing is national ownership, which is crucial for developing a solid strategic energy planning process and government buy-in of scenarios. Governments that are now developing internal modelling capacity can begin with using more basic methodologies—for instance, with an accounts-based model rather than a complex energy system optimisation model [136,137]. It is also relevant to discuss the use of proprietary tools (e.g., LEAP [138], TIMES [139]) and non-proprietary tools (e.g., SAM [140], NEMS [141], MESSAGE [142], OSeMOSYS [143]), the usual trade-off being the license costs and user support [144,145]. Insourcing scenario modelling capacity will guarantee that scenario developers experience closer and more frequent communication with high-level governmental energy planners; however, this can likely result in unambitious and conservative scenarios that are heavily influenced by government agendas.

In Mexico, the Secretariat of Energy (SENER) produces a yearly series of LTES [146] and is responsible for the National Energy Strategy [147]. SENER's inhouse energy planning team has benefitted from partnerships with, for example, the Danish Energy Agency for training in the BALMOREL capacity expansion model [148] and with IRENA to produce a roadmap to 2030 [149]. The United Kingdom insources scenario development capacity in the Department of Business, Energy and Industrial Strategy (BEIS) and produces a quality assurance guide for experts performing model analysis in the public sector [150].

Table 4 illustrates the four-step process of quality assured modelling analysis in BEIS. In Brazil, official scenario capacity is allocated in the Energy Research Office (EPE), an independent governmental agency that supports the Ministry of Mines and Energy (MME) in developing scenarios for the National Energy Plan 2050 [12] and the Ten-Year Energy Expansion Plans (PDE) [13]. The Netherlands Environmental Assessment Agency (PBL) is an autonomous government agency that houses its own internal scenario development capacity, resulting in national outlooks and other scenario analyses [151,152].

**Table 4.** The United Kingdom's four-step quality assurance (QA) framework for modelling in government.

| 1. Planning | 2. Expert Review | 3. Analytical Clearance | 4. Approval/ Sign-Off |
|---|---|---|---|
| - QA must be factored into project planning.<br>- Outcome: agreed roles, responsibilities, resources and timings; utilisation of appropriate expertise. | - Independent scrutiny of analysis and evidence.<br>- Ongoing revision process.<br>- Drawing on expertise from each relevant discipline.<br>- Peer reviews used to improve work. | - Statement that evidence within the project is adequate for its intended purpose (with any caveats).<br>- Based on peer review opinions and actions taken in response. | - Overall completion of a product.<br>- Factors in clearance statement, in addition to wider factors. |

#### 6.1.2. Outsourcing Scenario Development Capacity

Outsourcing scenario development effectively will require strong in-house (government) capacity to comprehend LTES and to ensure good contracting of consultants. Therefore, training scenario users is as important as training scenario developers. Outsourcing allows access to better models and building techniques; the drawback, however, is having black box tools, undermining of internal scenario capacity and creating a lock-in or over-reliance on a few consultancy companies that will fulfil the contractor's desires. Outsourcing also has the advantage of ensuring experts develop the LTES. Therefore, governments who cannot insource may begin with outsourcing and follow that with knowledge transfer activities, which can be supported through collaboration with academia and international institutions. In any case, when outsourcing, full disclosure of scenario data and modelling methodologies is recommended.

In Germany, the Ministry of Economy and Energy (BMWi) has highly-capable internal capacity to both comprehend and build LTES [153]. Yet, the country has the availability of multiple first-class energy research institutions that carry out independent scenario studies which can be compared to gain a wider range of insights [154–157]. The United

Arab Emirates Energy Strategy 2050 was developed using a proprietary modelling tool outsourced to consultancy firms; nevertheless, the energy strategy team in the Ministry of Energy and Industry is now in the process of building capacity to develop scenarios in-house [158]. IRENA's Masterplan Development Support Programme supported the development of the Kingdom of Eswatini Electricity Master Plan [159,160]; the International Energy Agency's Energy Technology Systems Analysis Programme (ETSAP) influenced Portugal's National Action Plan on Climate Change in 2014 and the Republic of Ireland's Climate Action and Low Carbon Development Act in 2015 [161].

## 7. Conclusions

The application of LTES to draw policy-relevant insight regarding the transition to a clean, sustainable and low-carbon energy and economic system is fraught with challenges. Scenario development models and tools are simplifications of a complex and dynamic real-world energy system, and results must be considered under the condition that transition features, such as higher shares of variable energy, electrification and new markets structures, are being considered in the analysis. However, the development and use of LTES to inform the transition goes beyond the modelling space. It demands robust energy governance, institutionalised energy planning processes and absorptive capacity in government to make use of complex insights. Operating under such technical and governance circumstances requires scenario practitioners to handle results with caution. These challenges notwithstanding, LTES remain a vital tool employed by government agencies as a basis for their decisions, plans and policies, and not only in the energy sector; LTES will surely play a critical supporting role to develop mid-term nationally determined contributions under Article 4.2 and long-term low greenhouse gas emission development strategies under Article 4.19 [162,163–165] in all participating nations of the Paris Agreement.

Despite the importance of LTES in national energy policymaking, there has been little effort to develop formal guidelines for their application in government. Best LTES practice is typically learned through replicating experience from other countries and apprenticeship with more experienced scenario users from academia, technical institutes, international development bodies and consultancies. By contrast, the literature shows that energy modelling has benefitted from efforts to standardise its approach (e.g., [166,167]), and served as a practical guide for modellers [168–170].

This paper is a first effort to document and formalise best practices regarding the use of LTES in the government in the energy transition context. We view such guidelines as an essential national energy planning resource, which we hope create a set of expectations for LTES-based analysis and the minimum considerations for effective LTES use. Best practice guidelines, however subjective and imperfect, also serve as a benchmark for methodological refinements and future debates.

The best practices listed in this paper draw upon the LTES literature and the first-hand experience from national energy institutions that are transforming their scenario practice as the energy policy landscape is driven by climate action. As the transition continues to unfold, new approaches will likely need to be developed to tackle even more ambitious climate goals and the profound socioeconomic and infrastructure challenges that arise. Best practices for LTES in the government will evolve as the discussion involves more people, tools and models are refined and the climate policy landscape changes.

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