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LTES LONG-TERM SCENARIOS FOR THE ENERGY TRANSITION

AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

IRENA International Renewable Energy Agency

Insights from net-zero LTES for national energy planning

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The report Benchmarking net-zero scenarios showcased overarching trends that are common in decarbonisation pathways:

- End-use sector electrification.
- Energy efficiency improvements.
- High shares of renewable energy.

However, it is important to delve further into the enabling factors for such trends:

- Digitalisation.
- Decentralization.
- Behavioural changes.

Are some of the key factors in enabling the energy transition.

Have net-zero scenarios begun to showcase these elements? Are governments actively including such enabling factors in their long-term planning?

This event will bring together experts to explore how net-zero LTES can be analysed and compared to produce useful insights for ambitious policymaking:

- *What are the key elements that constitute net-zero LTES and how can they be incorporated for national planning purposes?*
- *In devising net-zero scenarios, what are the key methodological challenges? What lessons can we learn for national net-zero scenario development?*

Welcome remarks, Dolf Gielen, IRENA

Dolf Gielen from IRENA presented an overview of the urgent need for effective energy transition strategies to achieve net-zero emissions, highlighting six key strategies from the 2022 World Energy Transitions Outlook: energy efficiency, renewable power, electrification, green hydrogen, bioenergy, and carbon dioxide removal. He identified six significant challenges that impact energy planning and modeling:

1. **Integration of Variable Renewables**: Ensuring power system flexibility across various timescales as renewables grow.
2. **Role of Natural Gas and Hydrogen**: Deciding whether to transport green hydrogen or relocate industries closer to production sites.

3. **Optimizing Biomass Use**: Balancing biofuels' role in emission reduction while addressing natural carbon cycles.
4. **Building Renovation for Energy Efficiency**: Addressing data gaps in city energy modeling and renovation barriers.
5. **Smart Charging for Electromobility**: Developing incentives and infrastructure for efficient EV charging.
6. **CCS Deployment**: Integrating CCS into models despite its slow uptake.

Gielen emphasized the need for energy planning models that capture both technical and socioeconomic dimensions, such as job creation and local economic impact, which requires combining multiple analytical approaches.

He underscored that effective energy planning is a structured, transparent process involving scenario analysis, not just a tool that produces numerical outputs. A global initiative, the Long-Term Low Emission Development Strategies (LT-LEDS), now includes 51 countries, and IRENA's LTES initiative aims to enhance best practices in scenario development and modeling.

Moving forward, IRENA will focus on four areas to support energy transition planning: aggregating scenario findings, promoting cross-sectoral knowledge exchange, refining stakeholder engagement practices, and improving modeling accuracy, particularly for infrastructure, behavior, and systemic innovation. Gielen invited global participation in the LTES dialogue, recognizing that as the energy transition progresses, the need for adaptable and insightful energy planning grows.

Scene-setting presentation, Asami Miketa, IRENA.

Asami Miketa from IRENA discussed the importance of net-zero scenarios in national energy planning, aligning with the Paris Agreement's goal of limiting global warming to 1.5°C. She highlighted key challenges and priorities in scenario development based on IRENA's latest surveys and scenario comparison studies, emphasizing that reaching net zero by mid-century requires enhanced national strategies that integrate comprehensive energy planning.

Key insights from IRENA's research and scenario comparison studies include:

1. **Electrification and Renewables**: There is broad agreement on the importance of power sector decarbonization with renewables and electrifying end-use sectors such as transport, buildings, and industry.
2. **Diverging Strategies**: Differences emerge mainly in end-use electrification and the reliance on alternative decarbonization options, driven by differing assumptions on technological success and policy choices.

3. **Expanded Scenario Scope**: Experts suggested expanding net-zero scenarios to include disruptive demand-side changes, systemic innovations, consumer behavior shifts, and policy adaptation, pushing beyond traditional energy models.
4. **Infrastructure Trade-offs**: Miketa noted that infrastructure requirements vary between pathways, such as hydrogen production and synthetic fuels, and models often overlook the implications of location and transportation trade-offs.

IRENA's latest World Energy Transition Outlook identifies six key technology avenues, emphasizing renewables, electrification, and the strategic use of hydrogen**. Miketa underlined the need for digitalization and decentralized innovation, highlighting how these can increase system flexibility** and integrate consumers into the energy transition.

Miketa also addressed current gaps in national energy planning, pointing out that only a few G20 countries have robust, scenario-based plans extending to 2050. To support this, IRENA has introduced a National Energy Transition Planning Dashboard in collaboration with UNFCCC to benchmark and evaluate these plans. Concluding, Miketa invited insights from experts on designing effective net-zero scenarios, particularly regarding challenges, narratives, and advice for practitioners in IRENA's Long-Term Energy Scenario (LTES) Network.

Expert interventions:

Moderator:

- Tiina Koljonen, Research Team Leader and Principal Scientist – Scenario planning to carbon-neutrality, VTT Technical Research Centre of Finland

Experts:

- Brian O'Gallachoir, Chair of the Executive Committee of the IEA Energy Technology Systems Analysis Program on energy systems modelling (IEA-ETSAP) and Professor of Energy Engineering in University College Cork
- Todd Levin, Principal Energy Systems Engineer, Argonne National Laboratory / Net-Zero World Initiative
- Pablo Carvajal, Senior Manager – Climate change and Sustainable Finance, Ernst & Young LLP (EY)

Tiina Koljonen from Finland's VTT Technical Research Centre introduced the session by framing key topics for discussion on developing effective net-zero scenarios. **She highlighted the need for clarity around the definition of "net zero,"** as interpretations vary widely across countries and may include or exclude different greenhouse gases, land use changes, and offsets.

Koljonen provided Finland as an example, where the climate neutrality target aims for net zero by 2035 and a climate-negative status after that. Finland's approach includes all greenhouse gases and land-use

changes but excludes offsets, distinguishing it from other countries. Additionally, Finland has legislated a coal phase-out by 2029, which impacts its baseline or "business as usual" scenario in energy planning.

Koljonen emphasized that **evolving net-zero scenario narratives bring unique methodological challenges for national planners**, particularly in distinguishing these scenarios from conventional "business as usual" models. She introduced Professor Brian O'Callaghan, chair of the IEA Energy Technology System Analysis Program (ETSAP), to share insights on methodological approaches from his work at the University of Cork and with IEA ETSAP

Brian O'Gallachoir, representing the IEA-ETSAP, presented on the methodological progress and ongoing challenges in long-term energy systems modeling, particularly within the context of global net-zero goals and national planning.

1. **ETSAP Community and Modeling Focus**: ETSAP, a technology collaboration program of the International Energy Agency (IEA), has evolved since the 1970s to focus primarily on greenhouse gas (GHG) reduction in the energy sector, with nearly 200 modeling teams across 70 countries. Using Energy Systems Optimization Modeling (ESOM) tools, specifically the TIMES model, ETSAP assesses cost-efficient pathways for energy system transitions, integrating over 1,300 technologies spanning both demand and supply sides of energy use.
2. **Comprehensive Energy System Analysis**: Unlike models that center on the power sector, TIMES adopts a holistic approach, considering all energy sectors. This co-optimization of electricity and other energy forms is especially beneficial for assessing electrification as a decarbonization strategy. O'Gallachoir underscored that models must address total GHG emissions, not merely energy or electricity-related emissions, to avoid oversights—highlighting, for instance, Ireland's unique emissions challenges where agriculture contributes significantly to national emissions.
3. **Insights from National and Global Net-Zero Scenarios**: Drawing from ETSAP's collective modeling work, several findings were highlighted:
    - **Global Pathways**: Immediate action is essential for meeting 1.5°C goals, and negative emissions technologies (NETs) will be vital, though they cannot replace immediate mitigation efforts. Demand-side emission reductions and energy consumption cuts were also identified as critical.
    - **National Variability**: Common trends include electrification and decarbonizing electricity, though each country faces unique challenges. For example, Denmark's focus on banning internal combustion engines, Switzerland's emphasis on power-to-gas innovations, and Canada's emphasis on inter-jurisdictional cooperation each illustrate tailored national responses.
4. **Methodological Strengths and Challenges**: O'Gallachoir noted that TIMES' ability to co-optimize across sectors and the global collaboration within the ETSAP community enable robust energy modeling insights. Nonetheless, significant challenges persist, particularly in:

- **Societal Factors**: There are gaps in understanding societal impacts and acceptance of energy transition pathways.
- **Energy Security**: Balancing energy security with climate goals, particularly the urgent shift from fossil fuels due to geopolitical events (e.g., the need to reduce reliance on Russian energy sources).
- **Mission-Oriented Decarbonization**: Reflecting on the rapid response to COVID-19, he advocated for a similar urgent, mission-driven approach to climate mitigation, noting that purely cost-based solutions may fall short in the face of climate emergencies.

These reflections from the ETSAP community emphasize the need for an integrative, urgent, and socially-informed approach to achieving national and global net-zero ambitions.

Todd Levin, energy systems engineer at Argonne National Laboratory, provided insights on modeling challenges within the U.S. Department of Energy's new "Net Zero World Initiative," aimed at accelerating global energy decarbonization. Levin highlighted five key challenges in energy system modeling for net-zero scenarios, emphasizing that models must be viewed as decision-support tools rather than definitive solutions.

1. **Data Considerations**: Levin emphasized data's critical role, noting that data collection, management, and quality can account for a substantial portion of modeling efforts. Specific challenges in net-zero modeling include:
    - Increased importance of data on wind, solar, and land use as these resources grow in scale.
    - Supply chain and critical material needs, especially for batteries and biomass, as well as access to non-traditional fuels like hydrogen.
2. **Model Assumptions and Uncertainty**: Model assumptions, such as future technology costs and demand forecasts, shape results but carry significant uncertainty, especially over long timeframes. For net-zero models, assumptions around emissions definitions (direct vs. life cycle), negative emissions, and technology cost projections are critical but remain fluid. Levin suggested transparent assumption-setting to aid interpretation and scenario flexibility.
3. **Scenario Design**: Robust scenario design is essential for understanding sensitivities and uncertainties. Different decarbonization pathways (e.g., wind and solar plus storage, nuclear, carbon capture and storage) can yield diverse outcomes. In net-zero contexts, scenario design must anticipate extreme variations in pathways and combinations of energy technologies to maintain relevance and adaptability.
4. **System Representation**: Simplifications are necessary but require careful alignment with real-world complexities. For net-zero modeling, longer time horizons add layers of complexity, including:

- The growing importance of socio-political factors, land use, and implementation barriers.
- Reliability challenges for power systems, where newer technologies like solar and batteries require updated metrics to ensure reliability.
- Approaches to model the net-zero goal itself (e.g., setting it as a strict constraint or a ramp-up target) impact feasibility and realism.

5. **Interpretation of Results**: Levin stressed that model outputs should be viewed as guides for decision-making rather than absolute answers. Accurate communication of model limitations is key, particularly for net-zero outcomes that may differ markedly from current norms and be challenging for non-technical audiences to interpret. Levin advocated for frequent revision and adaptation of models to new data, ensuring models serve as evolving, flexible guides for policymakers.

In summary, Levin's presentation underscored that energy system models, especially for net-zero planning, require extensive data, scenario adaptability, and interpretative caution to serve as effective, actionable tools for long-term policy planning.

Pablo Carvajal from Ernst & Young discussed the evolving role of climate scenarios in the financial sector, tracing their emergence since the Paris Agreement's call to align finance with climate goals. His presentation covered how long-term climate scenarios, traditionally unfamiliar to the private sector, are now essential for risk management, strategic planning, and setting climate targets.

1. **Background on Climate Scenarios in Finance**: The Paris Agreement catalyzed the need for climate-aligned finance, leading to the formation of the Task Force on Climate-Related Financial Disclosures (TCFD), which promotes scenario analysis as a standard tool for understanding climate risks and opportunities in finance. Carvajal noted that financial institutions now utilize climate scenarios primarily for:
    - **Risk and Opportunity Management**: Assessing potential impacts of climate change on portfolios and assets.
    - **Business Strategy and Target Setting**: Setting internal targets by aligning with climate scenario trajectories from organizations like IRENA, IEA, and IPCC.
2. **Challenges in Applying Climate Scenarios**:
    - **Data Granularity and Policy Pathways**: High-level scenarios often lack specific policy and technological actions needed for corporate-level decision-making. Carvajal emphasized the need for detailed, step-by-step policy action guidelines to help firms interpret and implement scenario-based adjustments.
    - **Transition and Physical Risks**: Financial stakeholders need scenarios that account for both transition risks (such as policy shifts or technological advances) and physical risks from climate impacts (e.g., acute weather events). Scenarios should ideally provide two

types of net-zero pathways: an “orderly transition” with consistent policy progression and a “disorderly transition” reflecting delayed or inconsistent actions.

3. **Need for Alternative Net-Zero Scenarios**: Carvajal highlighted that the private sector benefits from multiple net-zero scenarios that incorporate different transition speeds and methods (e.g., rapid CCS deployment in later decades versus steady early decarbonization). These alternatives could inform national planning by illustrating the various risks and decision points under differing climate action pathways.

4. **Integrating Physical Risks into Business-as-Usual Scenarios**: Traditional business-as-usual (BAU) scenarios often lack an assessment of the severe socio-economic impacts if climate goals are missed. Carvajal suggested including these physical risks in BAU scenarios to underscore the real costs of a failed transition and guide the financial sector on managing associated risks.

5. **Setting Science-Based Targets**: Many corporations use climate scenarios as benchmarks to align their emissions targets with scientific projections. Carvajal explained that the Science Based Targets initiative allows companies to set targets based on scenario rates of decarbonization (e.g., sectoral benchmarks on electrification or industrial decarbonization). This approach, especially popular in Europe, often aligns corporate targets with accelerated regional transitions like those from the EU, OECD, or JRC.

6. **Differing Interpretations of Scenarios Between Sectors**: Carvajal noted a gap between how development and climate modeling communities understand scenarios and how the private sector uses them. For researchers and policymakers, scenarios represent system models used for planning and investment analysis, while for the private sector, “scenario analysis” translates high-level climate scenarios into actionable, quantified outcomes. He emphasized the importance of national-level tools and support for aligning corporate actions with broader climate goals, thus enabling a more comprehensive transition of the real economy.

In conclusion, Carvajal underscored the private sector’s need for clear, actionable guidance from national and international scenarios, which could help bridge the divide between high-level modeling and concrete, business-focused decision-making.

Moderator, Tiina Koljonen posed two combined questions from the audience for all panelists to address:

1. **Net-Zero Target Definition**: Koljonen highlighted the complexity of defining net-zero targets, noting that these targets often balance scientific data on cumulative emissions with political considerations, as illustrated by Finland’s politically influenced net-zero timeline. She asked the panelists to comment on whether this is the best approach to defining net-zero timelines.

2. **Addressing Uncertainty**: Koljonen inquired about methods to address uncertainty in scenario modeling, referencing "robust decision making" as one approach and inviting panelists to suggest additional techniques for dealing with uncertainties in long-term scenarios.

Brian O'Gallachoir

- **Net-Zero Target Definition**: O'Gallachoir noted that cumulative emissions are more critical for limiting global warming than the specific timeline for achieving net-zero. However, net-zero by a specific year remains a convenient and accessible policy metric. He highlighted Ireland's recent climate legislation as an example of combining cumulative emissions targets with traditional net-zero deadlines. Ireland has set a carbon neutrality goal for 2050, alongside a specific emissions reduction target of 51% by 2030, reinforced by five-year carbon budgets. He commended this approach for aligning year-specific targets with cumulative emissions goals, though acknowledged the accessibility challenges of cumulative metrics for policymakers.

- **Addressing Uncertainty and Societal Buy-in**: In response to the question on uncertainty, O'Gallachoir suggested adopting novel decision-making frameworks, such as "robust decision-making" and mission-oriented strategies. Reflecting on COVID-19 responses, he noted that effective pandemic policies involved rapid, strategic measures with clear communication and societal engagement. He argued that similar methods are essential for climate policy to ensure public acceptance and adherence to ambitious climate actions. In conclusion, he emphasized **that in addition to addressing uncertainty, gaining societal buy-in is crucial for the success of net-zero targets and policies.**

Todd Levin provided an objective, modeling-focused perspective on defining net-zero targets and handling uncertainty in long-term scenarios.

1. **Net-Zero Definition and Policy Implications**: Levin emphasized the importance of clearly defining net-zero goals, particularly regarding timing, pathways, and implementation details. He suggested that, as a modeler, his role is to analyze and communicate the implications of different net-zero definitions to policymakers. He noted that if cumulative emissions reduction is the true objective, models can help illustrate how different net-zero definitions impact cumulative emissions. Levin stressed that while modelers can inform and analyze policy, determining the "best" policy requires balancing other non-technical considerations.

2. **Addressing Uncertainty**: Levin highlighted the extensive uncertainty within energy transition modeling and emphasized transparency through scenario and sensitivity analyses to illustrate the range of potential outcomes. By presenting this range, modelers can help policymakers understand the uncertainties inherent in the transition and the importance of adaptability as new data and scenarios emerge.

In closing, Levin reiterated that communicating these uncertainties and diverse potential outcomes is crucial for informed, flexible policymaking in the net-zero transition.

Koljonen then asked Carvajal if he had additional thoughts on defining net-zero, especially given his view on its potential as a new reference scenario, or if he could share further insights on managing uncertainty, building on points he had already mentioned in his presentation.

Pablo Carvajal expanded on the concept of using net-zero as a reference scenario, particularly emphasizing near-term targets and the nature of uncertainties in modeling.

1. **Net-Zero as a Reference and Focus on 2030 Targets**: Carvajal highlighted how the financial sector, exemplified by the Net-Zero Banking Alliance (NZBA), often sets ambitious interim targets for 2030 rather than fixed 2050 goals, under the assumption that net-zero by mid-century will be achieved collectively. He pointed out that, based on scenario comparisons, consistency among pathways generally improves by 2050, whereas 2030 targets vary widely. This makes near-term (2030) targets especially crucial for monitoring progress and understanding different transition speeds, providing clarity on whether countries or organizations are on a faster or delayed path to net-zero.
2. **Clarifying Model Uncertainties**: Carvajal categorized modeling uncertainties into two main sources:
    - **Data Uncertainty**: Relating to the quality or availability of data, where improved data collection is the main solution.
    - **Model Structural Uncertainty**: Arising from the way models represent reality. To address this, Carvajal suggested running multiple models on the same data and system to observe differences in outcomes. He referenced a study that applied 15 models to the same data, finding variations in results, though trends and insights were generally aligned. This supports the idea that models are valuable primarily for insights rather than specific numbers, resonating with Brian O'Gallachoir's earlier point about focusing on directional insights in modeling.

Carvajal concluded that using multiple models and methodologies where possible can help gauge the range of uncertainty, thereby strengthening the robustness of scenario analysis in the net-zero planning process.

Tiina Koljonen's Closing Question (VTT Technical Research Centre of Finland): As the session neared its conclusion, Tiina Koljonen requested brief, two-sentence recommendations from each panelist. She asked them to share final thoughts on how the Long-Term Energy Scenarios (LTES) network could effectively support national governments and other stakeholders in strategic decision-making and policy development.

Koljonen's request focused on actionable insights for enhancing LTES's role in aiding national and stakeholder strategies, aiming to conclude with concise guidance from each panelist.

Brian O'Gallachoir emphasized that the LTES network's primary role should be to offer accessible, independent advice to policymakers. He suggested fostering open communication, where policymakers

can share their challenges and receive honest guidance on what models can and cannot achieve, positioning the network as a supportive resource rather than a directive entity.

Todd Levin advocated for a stronger, ongoing dialogue between modelers and policymakers, emphasizing the advantage of involving technical analysis throughout the policy development process rather than using it solely as a response tool. He recommended a collaborative approach, where technical, financial, and developmental stakeholders work closely to create cohesive, well-informed policies that can achieve shared net-zero goals efficiently.

Pablo Carvajal recommended that the LTES network actively engage the private sector, particularly to explore how scenarios can be applied in corporate and financial contexts. He highlighted the value of connecting existing frameworks (e.g., the Science-Based Targets initiative) with scenarios from organizations like IRENA, IEA, and national agencies, helping the private sector understand and integrate these models into their decision-making processes. Engaging with private stakeholders in this way, he suggested, would enhance the practical utility of energy scenarios for financial and corporate planning.