Building Resilient Energy Policies in Asia-Pacific

APEC Energy Working Group

April 2026

Asia-Pacific
Economic Cooperation

Asia-Pacific
Economic Cooperation

Building Resilient Energy Policies in Asia-Pacific

APEC Energy Working Group

April 2026

APEC Project: EWG 104 2024A

Produced by
Felipe Feijoo, Ph.D., Abhishake Kundu, Ph.D., Francisco Flores, Ph.D, and Paola Paredes.
School of Industrial Engineering, Pontificia Universidad Católica de Valparaíso
Ignacio Soto Morales

Isabella Villanueva García
Planning and Climate Change Unit, Ministry of Energy of Chile

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org

APEC#226-RE-01.2

Acknowledgements

This publication was funded by APEC. The views expressed in this publication are the authors' alone and are not necessarily the views of APEC. The authors wish to acknowledge the contributions and support of Paula Vega, Martín Salazar, Pía Fuentes, and Valentina Fuenzalida. They supported key tasks, including technical assistance, data collection, and analysis, and contributed directly to drafting and reviewing sections of the document. Authors also wish to acknowledge all reviewers and feedback received during the review of the report.

Reference

This report can be referenced as:

Feijoo F., et al. (2026) *Building resilient energy policies in Asia-Pacific*. Technical Report, report to APEC.

Contents

List of Tables

List of Figures

Executive Summary

APEC energy systems are facing fast growing electricity demand, intensifying climate and disaster risks, greater digital and cyber exposure, and rapidly changing energy markets. In this context, resilience has become a central pillar of energy policy. It is needed not only to protect people, firms, and critical services during shocks, but also to enable credible pathways toward net zero emissions. This report uses the APEC Energy Resiliency Principles together with reference concepts from IPCC, IEA, CDRI, and CIGRE to examine how selected APEC economies are incorporating resilience into their energy policies, planning and regulation.

Resilience in this report is understood as the capacity of energy systems to anticipate shocks, withstand and limit their impacts, and recover in ways that reduce future vulnerability. The analysis focuses on four main dimensions. The first is robustness of infrastructure and system operation. The second is flexibility and adaptability, through diversified generation, storage, demand response, and distributed resources. The third is recovery capacity, reflected in how quickly and reliably service is restored after disruptions. The fourth is governance and regulation, which determine whether resilience is translated from high level goals into concrete planning criteria, standards and investments.

Using this framework, the report conducts an economy-by-economy APEC assessment on resilience regulations. It reviews energy and climate laws, regional strategies, disaster risk management frameworks, long term power development plans, grid codes, and the quality of service indicators. In some economies, such as Australia; Japan; The Republic of the Philippines; Singapore; and United States resilience is already named as a policy objective and is supported by specific planning tools, regulatory mechanisms and funding programs. In others, including Brunei Darussalam; Malaysia; Peru; and The Russian Federation resilience is addressed mainly through the language of reliability, security of supply and climate adaptation, even though many of the practical measures are similar.

Several common features emerge across the case studies. All the economies face growing climate and natural hazards that affect power systems, including floods, storms, droughts, wildfires, landslides, heat waves, sea level rise and earthquakes. Most of the economies already treat electricity as critical infrastructure in their disaster and climate laws, and many assigns explicit responsibilities to energy authorities, regulators and operators. Reliability is routinely monitored through indicators such as SAIDI (total outage time), SAIFI (outage frequency), CAIDI (restoration time), MAIFI (momentary outages), and ENS (Energy Not Supplied), alongside generation adequacy indicators (LOLP, LOLE). Almost all the economies have adopted decarbonization or energy transition goals and are expanding renewable generation, efficiency and electrification. Technical solutions such as digital system monitoring, large batteries, pumped storage, microgrids, and distributed renewables appear repeatedly as tools to strengthen resilience.

The report also highlights important differences that shape distinct resilience pathways. One key difference is system maturity and the link between resilience and access. Economies with large interconnected systems and near universal access focus on reinforcing ageing infrastructure, managing extreme weather and cyber threats, and integrating high shares of variable renewables while avoiding major blackouts. Other economies still face low access levels or marked gaps in service quality between urban and rural areas. In these contexts, resilience and access cannot be separated.

A second difference concerns generation mixes and dependence on fossil fuels and imports. Economies with high shares of hydropower and other renewables need to manage hydrological variability and balancing challenges that are amplified by climate change. Economies that remain anchored in coal and gas face resilience risks related to fuel supply chains, price volatility, and possible interruptions caused by extreme weather or geopolitical tensions. Rapid growth of renewables without matching investment in flexibility and networks can also create new vulnerabilities, including congestion, curtailment and tighter operating margins. The analysis shows that resilience and decarbonization must be planned together so that the transition reduces overall exposure to fuel and climate risks rather than shifting them to other parts of the system.

Governance and market structures further shape how resilience is handled in practice. In economies with liberalized or partially liberalized power markets and independent system operators, resilience is increasingly discussed as a policy and regulatory priority, supported in some cases by standards, guidelines, or targeted programs [1]. In economies where state owned utilities dominate generation, transmission and distribution, resilience is often embedded directly in regional energy strategies, energy security doctrines and utility investment plans. This can in principle align regional goals and investments more easily, but it also means that progress depends strongly on the financial health, technical capacity and priorities of a small number of institutions and on the stability of public budgets.

From these findings, the report draws a set of summary messages for APEC economies and for their regional cooperation. Resilience should be made an explicit objective in energy policy, regulation and planning, using a language that recognizes climate and disaster risks, the need for flexibility and redundancy, the importance of recovery capacity and the role of strong governance. Climate and hazard information must be systematically integrated into infrastructure planning, design and operation so that assets are prepared for future conditions, not only for historic averages. Resilience and decarbonization should be treated as mutually reinforcing. Transition pathways need to reduce dependence on vulnerable fuels and supply chains and provide sufficient flexibility, storage, and grid capacity for systems with high shares of renewables. In economies that still face access gaps, electrification strategies should favor robust solutions in remote and hazard prone areas, including decentralized and community-based systems that can withstand local shocks. Metrics and monitoring should be improved by complementing traditional reliability indicators with measures of performance during and after extreme events and of the speed and quality of recovery.

1. Introduction

Recent events show that energy resilience is not an abstract concept but a very concrete problem that can put entire societies on pause. In February 2021, Winter Storm Uri exposed deep weaknesses in the Texas power system. Poorly winterized gas plants, frozen equipment and limited interconnections led to one of the worst energy crises in United States history, leaving more than four and a half million homes and businesses without power for days in sub-zero temperatures and causing hundreds of deaths and very large economic losses.

Similar patterns appear across other regions. On 25 February 2025, Chile suffered a near economy-wide blackout after a failure in protection systems triggered the disconnection of a key five hundred kilovolt transmission line and a cascade of generator trips. The outage affected about ninety-eight percent of the population, paralyzed the Santiago metro, disrupted copper mining and forced the government to declare a state of emergency and a night curfew while power was gradually restored. In Brazil, a disturbance on 15 August 2023 opened a five hundred kilovolt circuit near Imperatriz and split the local grid, cutting around nineteen gigawatts of load and affecting almost all states. A second economy-wide outage in October 2025, caused by a fire in a reactor at the Bateias substation, again demonstrated how a single point of failure in the transmission system can propagate through the National Interconnected System (SEN) and disrupt transport, water supply and communications.

Europe has faced its own stress tests. In April 2025 a voltage surge and planning mistakes in southern Spain triggered a rapid cascade that brought down about sixty percent of Spanish electricity supply and caused a widespread blackout that also hit Portugal through the interconnected Iberian grid. Authorities later concluded that the crisis reflected weaknesses in system planning and operational reserves, not a cyberattack. Only a few months earlier, extreme floods in the Valencia region had already damaged power infrastructure and other critical assets so severely that emergency funds and dedicated finance were needed to rebuild and make networks more climate resilient.

Taken together, these events show a common story. Different geographies and market designs face distinct hazards, from cold snaps and wildfires to storms and floods, but the underlying vulnerabilities are similar. High dependence on a narrow set of fuels, aging or exposed transmission corridors, protection schemes that do not fully account for new operating conditions and limited redundancy all increase the probability that an extreme event or technical fault turns into a large-scale outage. This is the motivation for placing resilience at the center of energy policy in APEC (see Figure 1). The challenge is not only to keep the lights on under normal conditions, but to design, regulate and operate systems that can anticipate shocks, absorb them, limit cascading failures and recover quickly while societies face a changing climate and a rapid transition in their energy mix.

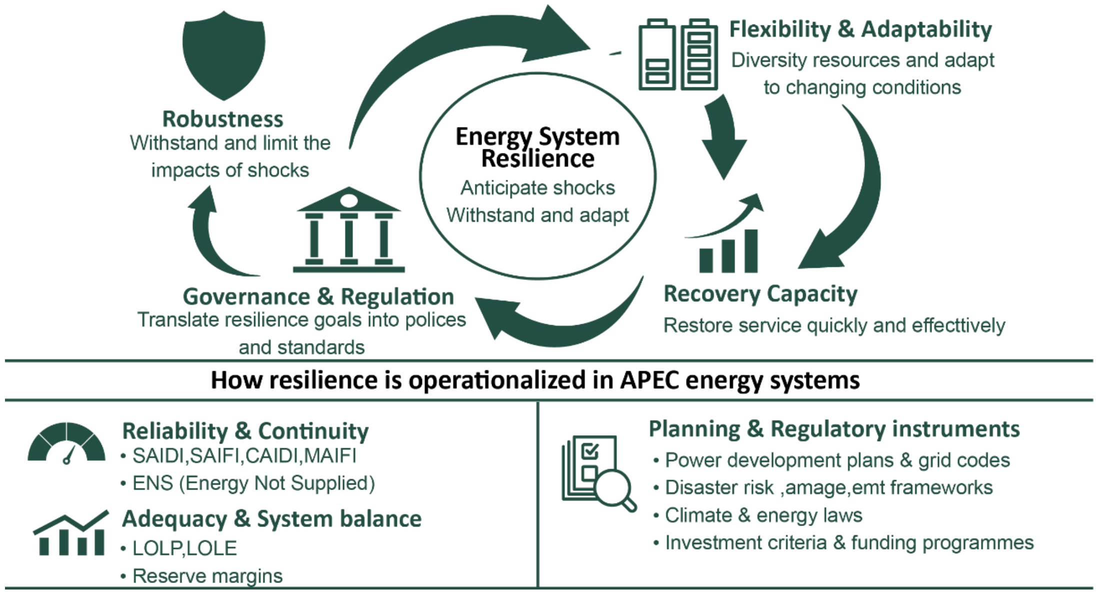

Figure 1 An overview of the key dimensions of energy system resilience and its operationalization in APEC economies.

2. A comparative analytical foundation for understanding energy resilience in APEC economies

Across the Asia–Pacific region, energy resilience has become a central organizing concept for energy policy, particularly within the framework articulated by APEC. The APEC Energy Resiliency Principle (see Figure 2) defines energy resiliency as the ability and quality that enables energy systems to withstand extreme natural and man-made disasters, to recover and return to normal conditions in a timely and efficient manner, and to "build back better," thereby securing a stable energy supply and minimizing negative impacts on human lives and socio-economic activities [2]. This definition places strong emphasis not only on resistance and recovery, but also on learning, improvement, and long-term system strengthening, aligning energy resilience with both energy security and sustainable development objectives.

Other international bodies provide complementary perspectives that broaden and reinforce APEC's approach. The IPCC defines resilience more generally as the capacity of social, economic, and environmental systems to cope with hazardous events or trends by responding or reorganizing in ways that maintain essential functions, identity, and structure, while retaining the capacity for adaptation, learning, and transformation. The International Energy Agency (IEA) adds a climate-specific lens, defining climate resilience as the ability to anticipate, absorb, accommodate, and recover from climate-related hazards, and applying this concept to energy systems that can operate under extreme events, address slow-onset climate changes, and restore functionality afterward [3, 4]. Similarly, the Coalition for Disaster Resilient Infrastructure (CDRI) frames disaster resilience as the ability of systems and societies to resist, absorb, adapt, transform, and recover from hazards in a timely and efficient manner while reducing overall risk [5]. In the power sector specifically, CIGRE emphasizes resilience as the capability of electricity systems to limit the extent, severity, and duration of performance degradation following extreme events [6].

Taken together, these perspectives converge on a shared understanding that closely mirrors and strengthens APEC's Energy Resiliency Principle. Resilient energy systems are those that anticipate and prepare for climate and disaster risks, limit disruptions when hazards occur, restore critical services rapidly, and improve over time through learning and adaptation. Within APEC, this integrated view supports a holistic, multi-stakeholder approach to energy resilience that links disaster risk reduction, climate adaptation, energy security, and sustainable economic development across diverse regional contexts [2].

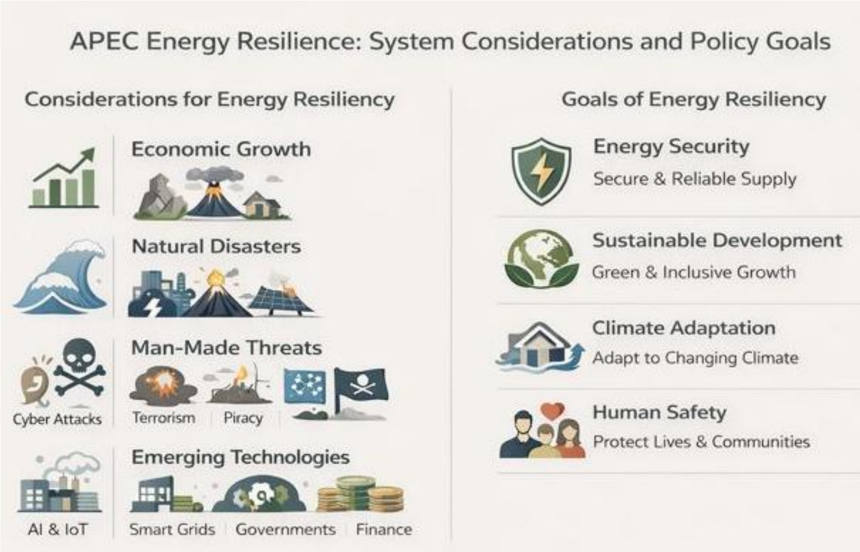

Figure 2 An overview of the APEC Resiliency Principles: system considerations and goals.

While climate change and climate-related hazards are an increasingly important driver of resilience considerations, the APEC Energy Resiliency Principle frames energy resiliency in a broader and more comprehensive manner. Under the APEC definition, energy resiliency refers to the ability and quality that enable energy systems to withstand extreme natural and man-made disasters, recover and return to normal conditions in a timely and efficient manner, and build back better, thereby securing a stable energy supply and reducing negative impacts on human lives and economic activities. In this context, climate hazards represent one important category of risk, but not the sole determinant of energy resilience in APEC economies.

Energy systems across the APEC region must remain reliable, affordable and secure under a wide range of stressors, including extreme weather events, earthquakes and other natural hazards, fuel supply disruptions, infrastructure ageing, market volatility, cyber threats and operational failures. Consistent with the APEC principle's emphasis on holistic approaches spanning both supply-side and demand-side measures, resilience intersects closely with energy security, long-term system planning and investment, infrastructure management, and the ongoing energy transition. Energy resilience in APEC economies is therefore not limited to climate adaptation but reflects a core system attribute that supports sustainable development and access under diverse and evolving risk conditions.

Within this broader framing, climate change nonetheless provides an essential backdrop for APEC economies, as it is altering the frequency, intensity and spatial distribution of hazards that directly affect energy infrastructure, supply chains and system operations. Climate-related stresses increasingly interact with existing vulnerabilities in energy systems, amplifying the consequences of disruptions and challenging recovery efforts. The following discussion draws selectively on the IPCC's regional assessments to illustrate the types of climate-related pressures already affecting energy systems across the APEC region. This overview is intended to provide contextual grounding rather than a comprehensive climate risk assessment, and to inform the subsequent analysis of how energy systems can be planned, operated and transformed, consistent with the APEC Energy Resiliency Principle to withstand shocks, recover effectively and improve over time in the face of multiple and interacting challenges.

APEC economies span diverse climatic and geographic conditions, and climate change is increasingly affecting the operating environment of their energy systems. Rising temperatures, changing rainfall patterns, and more frequent extreme events are placing growing stress on energy infrastructure and operations across the region. Higher temperatures increase peak electricity demand for cooling, reduce the efficiency of thermal power plants, and intensify strain on transmission and distribution networks. In coastal and island APEC economies, including parts of Southeast Asia, Oceania and the Pacific, sea level rise, storm surges and heavier rainfall raise the risk of flooding and damage to coastal power plants, LNG terminals, refineries and port-based fuel infrastructure. In typhoon- and cyclone-prone economies, more intense storms increase the likelihood of widespread outages and longer recovery times, affecting both electricity systems and fuel supply chains. In western North America and parts of Oceania, longer fire seasons and more severe wildfires threaten transmission corridors and distribution networks, while in colder and high-latitude economies, ground instability increases risks to pipelines and other long linear infrastructure. For economies with high dependence on hydropower, shifts in precipitation, glacier retreat and altered runoff patterns increase the probability of low-inflow years and multi-year shortages, with implications for both energy and water security. Across APEC, these climate-related stresses interact with existing challenges such as infrastructure ageing, rapid demand growth and limited redundancy, underscoring the importance of energy systems that can withstand disruptions, recover quickly and strengthen over time in line with the APEC Energy Resiliency Principle.

From an energy system and service continuity perspective, CDRI's work reinforces this picture from an infrastructure and service-continuity perspective and illustrates what power system resilience means in practice. It shows that as cyclones, floods and heatwaves intensify, the real economic damage often comes less from broken assets than from prolonged service disruption, with evidence suggesting that losses from outages can be several times higher than the direct cost of infrastructure damage [5, 7]. In the power sector this means that climate risk now affects the entire value chain: extreme heat drives record peaks in electricity demand for cooling while simultaneously reducing the performance of generators, transmission lines and transformers, a pattern documented in CDRI's scoping work on India's power system. Coastal grids face another layer of stress, as shown by detailed cyclone and flood mapping in Odisha, where large shares of transmission and distribution assets lie directly in high-hazard zones, demanding new design standards, asset-level risk metrics and targeted reinvestment to prevent repeated collapse. Regional and local initiatives, such as infrastructure resilience roadmaps and capacity-building programs for power-sector practitioners across the Indo-Pacific, demonstrate that resilience must be integrated into planning, regulation and investment decisions, not treated as a one-off project add-on [5]. This aligns closely with CIGRE's framing of power system resilience, which emphasizes actionable measures before, during and after extreme events to limit how far and how long system performance degrades [6]. For APEC economies, these experiences provide a practical foundation: they link climate and hazard science to concrete methods for assessing exposure, stresses and vulnerabilities in power systems, and show how the economies can move from reactive repairs after disasters to proactive, climate-informed planning that keeps electricity services functioning under a changing climate. For energy authorities, these experiences underline that resilience must be addressed systematically through planning frameworks, regulatory standards and investment decisions, rather than treated as an ad hoc response to individual disasters. These system-level impacts also have significant economic implications, highlighting the growing cost of declining reliability and the financial case for resilience-oriented investment

Beyond physical damage and service continuity, the economic cost of declining reliability provides a compelling rationale for embedding resilience into energy system planning and regulation. Globally, disaster-related losses now exceed USD 732 billion annually, with indirect economic losses estimated to be, on average, more than seven times higher than direct physical damages, reflecting the cascading effects of prolonged service disruptions across households, industry, and critical services [7]. In the infrastructure sector alone, average annual losses are estimated at USD 700–834 billion, with the energy sector accounting for approximately USD 100–110 billion per year. These losses are unevenly distributed but are particularly concentrated in economies with large and growing stocks of energy infrastructure, including many APEC members. Also, climate change is already amplifying these costs. Since the 1990s, higher cooling demand driven by rising temperatures has increased annual climate-related energy costs by nearly USD 20 billion, reflecting both higher peak loads and greater strain on power system assets. As extreme heat, storms, floods, and wildfires become more frequent and severe, the economic consequences of outages increasingly stem not from asset replacement costs alone, but from lost productivity, disrupted supply chains, and reduced welfare associated with unreliable energy services.

From an investment perspective, the evidence consistently shows that strengthening reliability and resilience is economically efficient. Multiple studies demonstrate that integrating resilience into infrastructure design typically increases upfront capital costs by only around 3 percent, while yielding benefit–cost ratios of approximately 4:1 or higher through avoided losses and improved service continuity [8,9]. Global assessments further suggest that every dollar invested in resilient infrastructure can generate between USD 4 and USD 6 in avoided future disaster costs, with some sector- and hazard-specific analyses reporting even higher returns. For example, investments aligned with modern, resilient design standards have been found to deliver returns of up to USD 11 per dollar invested in avoided losses, while World Bank estimates indicate that USD 1.8 trillion invested in resilient infrastructure globally could generate USD 7.1 trillion in net benefits [10]. These findings are particularly relevant for APEC economies, where infrastructure investment needs are expanding rapidly. Over the next two decades, the volume of new infrastructure built globally is expected to be comparable to that constructed over the past two centuries, creating a narrow but critical window to embed resilience at scale. For low- and middle-income economies, strengthening exposed infrastructure assets in the power, transport, and water sectors is estimated to increase annual investment needs by USD 11–65 billion, equivalent to around 3 percent of baseline infrastructure investment, an increment that is small relative to the potential reduction in long-term losses and service disruptions [9, 11]. In this context, resilience investments should be understood not as an additional cost, but as a core component of cost-effective, reliable and sustainable energy system development. From a mitigation and system transformation perspective, many APEC economies account for a substantial share of global energy-related emissions, largely due to the continued dominance of fossil fuels in power generation, industry, and transport. At the same time, declining costs of renewable energy, particularly solar and wind, have fundamentally changed the economic case for decarbonization across the region. In many APEC economies, new renewable generation is now cost-competitive with, or cheaper than fossil fuel-based alternatives. This creates an opportunity to pursue emissions reduction in ways that also strengthen energy resilience.

For APEC economies, deep transformation of the energy system involves large-scale deployment of renewables, increased electrification, improved energy efficiency, flexible demand management, and expanded storage and transmission capacity. If planned and implemented coherently, these measures can enhance resilience by reducing exposure to fuel supply disruptions, lowering dependence on cooling water, diversifying generation across locations and technologies, and enabling more distributed and modular system architectures that can isolate failures and recover more quickly after disruptions. Concepts developed by other international bodies, such as the IEA's focus on readiness, robustness, resourcefulness and recovery, reinforce the relevance of these levers for strengthening the resilience of energy systems undergoing transition [3, 4]. At the same time, there is no single, universally accepted framework for defining or operationalizing energy resilience. Different institutions emphasize different dimensions, including the types of hazards considered, the scope of the energy system, the phases of resilience, and the roles of planning, regulation, and investment. APEC's Energy Resiliency Principle distinguishes itself by explicitly combining disaster risk reduction, recovery and "build back better" approaches with respect for economic diversity, holistic supply- and demand-side measures, and multi-stakeholder processes. Table 1 is therefore used in this report as a comparative diagnostic tool to map key similarities and differences across leading resilience frameworks, while anchoring the analysis in the APEC context. The table focuses on different dimensions, including definition, analytical or measurement framework, and governance aspects.

Taken together, the evidence reviewed in this report points to a clear implication for APEC economies: Energy resilience is an immediate and growing policy challenge, not a distant or hypothetical concern. A wide range of hazards and system stresses are already affecting the reliability, safety and affordability of electricity and fuel supply across the region. At the same time, APEC economies have access to a broad portfolio of technical, operational, and investment options that can simultaneously support resilience and decarbonization. Building resilient energy systems in APEC therefore requires integrated planning that links infrastructure development, system operation, investment decisions and energy transition strategies, consistent with the APEC Energy Resiliency Principle and tailored to economy-specific circumstances.

Table 1 Resilience definitions

Dimension	**APEC – Energy resiliency**	**CDRI – Disaster resilience (DRI Lexicon)**	**CIGRE – Power system resilience**	**International Energy Agency (IEA)**
Core definition	Energy resiliency is described as the ability and quality that allows energy systems to withstand extreme natural and man-made disasters, to recover and return to normal conditions in a timely and efficient manner, and to "build back better", securing a stable energy supply and reducing negative impacts on human lives and economic activities.	Disaster resilience is defined as the ability of a system, community or society exposed to one or more hazards to resist, absorb, accommodate, adapt to, transform and recover from disasters in a timely and efficient manner that reduces risk and preserves or restores essential basic structures and functions.	CIGRE WG C4.47 defines power system resilience (as quoted in later literature) as "the ability to limit the extent, severity and duration of system degradation following an extreme event", focusing on how much and how long system performance degrades under extreme stress.	"The ability to anticipate, absorb, accommodate and recover from the effects of a potentially hazardous event related to climate change". A climate-resilient energy system is one that can prepare for changes in climate, adapt to and withstand slow-onset changes in climate patterns, continue to operate under immediate shocks from extreme weather events, and restore the system's function after climate-driven disruptions.
Analytical or measurement framework	Principles-based and qualitative framework emphasizing holistic assessment, stakeholder roles, resilience planning, and use of indicative indices and best practices rather than a single standardized quantitative metric.	Risk-based infrastructure resilience framework using hazard exposure, vulnerability, criticality and lifecycle considerations, supported by diagnostic tools and project-level resilience screening and performance indicators.	Technical power-system-focused framework assessing resilience through system performance metrics such as extent, severity and duration of degradation, recovery time, and ability to withstand and absorb extreme events.	Operational and planning-oriented framework using phase-based resilience assessment (readiness, robustness, resourcefulness, recovery), supported by system stress-testing, scenario analysis and policy and investment diagnostics.

Scale and governance emphasis	Strong policy and governance framing: emphasizes multi-stakeholder roles (governments, energy industries, consumers, financial institutions) and economy-wide planning, guidelines and investment frameworks for energy resiliency.	Embedded in disaster risk governance at multiple scales (local, regional, international), linking infrastructure planning, finance, policy and community-level practice; resilience is tied to DRI planning and investment decisions.	Focused on power system planning and operation, involving TSOs, DSOs, regulators and system operators; governance is expressed through system design standards, operational procedures and coordinated actions before, during and after extreme events.	IEA's approach is strongly policy- and governance-oriented. It introduces a Climate Resilience Policy Indicator to assess how well economies integrate climate resilience of energy systems into local energy and climate plans, regulations and investment frameworks. It emphasizes mainstreaming climate resilience into energy policies, mobilizing public and private finance, improving climate data and risk assessments, and coordinating actions among governments, regulators, utilities, investors and international partners.

Sources: APEC Energy Resiliency Principle, 2020); IPCC, 2022: Annex II – Glossary, in *Climate Change 2022: Impacts, Adaptation and Vulnerability* (AR6 WGII); CDRI (2023), *DRI Lexicon – Shared understanding of terms that matter for Disaster Resilient Infrastructure* ("Disaster resilience"); ETIP SNET (2022), *Flexibility for Resilience White Paper (CIGRE); IEA (2022), Climate Resilience Policy Indicator – Analysis (definition of "climate resilience" and "climate-resilient energy system"); IEA (2024), Climate Resilience for Energy Security in Southeast Asia (conceptual framework of energy-sector climate resilience and explicit four phases: readiness, robustness, resourcefulness, recovery)*

Across different regions, practical experience with climate and disaster risks shows how the conceptual definitions of resilience used by APEC, IEA, CDRI and CIGRE translate into real power-system decisions. In Odisha (India), joint work by the government and CDRI on coastal power networks exposed to cyclones and floods embodies CDRI's notion of disaster resilience as the ability to resist, absorb, accommodate, adapt, transform and recover. Detailed cyclone–flood hazard mapping against transmission and distribution assets led to prioritized reinforcement, undergrounding, updated design standards and modernization of critical lines. These measures operationalize CIGRE's power system resilience focus on limiting the extent, severity and duration of degradation during extreme events, while shifting from reactive repairs to proactive, climate-informed planning. Similarly, CDRI's work on extreme heat and India's power sector illustrates how resilience considerations can be translated into concrete energy planning, regulatory and operational measures. The analysis highlights the need for improved demand and generation forecasting under heatwave conditions, efficiency improvements in cooling technologies, the integration of flexible resources such as storage and demand response, and the revision of technical standards to manage the compound stresses associated with high temperatures, peak demand and asset derating. These measures underscore the central role of energy planning frameworks in anticipating system stresses, prioritizing investments and ensuring that power systems can continue to deliver reliable services under increasingly challenging operating conditions.

Regional and local initiatives show how energy resilience can be embedded in wider infrastructure and climate governance, in line with APEC and IPCC perspectives. Chile's roadmap for infrastructure resilience, developed with CDRI and UN partners, applies a multi-sector methodology that identifies high risk and cascading impacts in the water and energy sectors and proposes cross-cutting actions on governance, data and coordination, alongside sector-specific upgrades. This aligns with APEC's Energy Resiliency Principle, which treats resilience as a system-wide quality that protects stable energy supply and socio-economic activity, and with IPCC's vision of resilience as part of broader climate-resilient development pathways. In Southeast Asia, the IEA's climate resilience work for energy security translates its definition of climate-resilient energy systems (anticipate, absorb, accommodate, recover) into a four-phase framework (readiness, robustness, resourcefulness, recovery) that structures measures from improved climate-risk information and policy integration, through asset hardening and diversification, to flexible operation during shocks and rapid recovery. This provides a regional template for APEC economies to mainstream climate resilience into energy planning, consistent with IPCC and APEC views.

Finally, recent climate-driven outages in advanced power systems (for example, heatwaves and wildfires in parts of North America and Australia, or cyclones in Japan and Korea) reinforce that resilience is a universal challenge. These events illustrate that even high-reliability grids can fail when extremes exceed historical design assumptions, exactly the kind of situation envisaged in IPCC's emphasis on changing hazard profiles and CIGRE's focus on performance degradation under extreme events. IEA's Climate Resilience Policy Indicator responds by examining how economies integrate climate risks into energy and climate strategies, technical standards and operational practices, highlighting gaps even in mature systems. Taken together, the Odisha and India heat cases, the Chilean infrastructure roadmap, the IEA's Southeast Asia work and the experience of advanced grids show that the abstract definitions adopted by APEC, IPCC, IEA, CDRI and CIGRE are not purely conceptual: they already show concrete diagnostics, investments and governance reforms that APEC economies can adapt and scale to build energy systems that can withstand, recover from and learn from a growing range of climate and disaster risks.

3. Resilience in the energy policies of APEC economies

This section assesses how resilience is reflected in the energy policies of APEC economies and how far current frameworks are prepared for a more volatile future. Across the region, recent crises such as economy-wide blackouts, extreme cold events that froze power plants, wildfires that damaged transmission lines, and floods that overwhelmed substations have shown that traditional notions of reliability are no longer sufficient on their own. Energy systems must now cope with stronger and more frequent climate and weather extremes, rapid changes in generation portfolios, digital and cyber risks, and in some cases persistent access gaps. Against this backdrop, this section reviews how APEC economies define and operationalize energy resilience through laws, planning instruments and regulatory standards, building directly on the conceptual frameworks and system challenges discussed in the previous sections. The review examines how resilience objectives are translated into practice, including the types of risks considered, the performance indicators used to assess system outcomes, and the concrete measures adopted to anticipate shocks, limit cascading failures and restore energy services after disruptions. In particular, it highlights the links between resilience and traditional reliability metrics used by energy regulators, such as the System Average Interruption Duration Index (SAIDI), which provide an operational bridge between resilience concepts and service continuity experienced by consumers. Where relevant, the section also considers the cost and financing implications of resilience measures, recognizing that investment requirements, funding mechanisms and affordability considerations are central to embedding resilience in energy planning and regulatory decision-making.

3.1 Australia

Australia operates two main power systems, the National Electricity Market (NEM) and the Wholesale Electricity Market (WEM), whose operation and planning are the responsibility of AEMO (Australian Energy Market Operator), except for the State of Victoria [12]. In Victoria, from 1 November 2025, responsibility for transmission planning was delegated to VicGrid under the Victorian Transmission Investment Framework (VTIF), with the aim of accelerating the energy transition and achieving net-zero emissions targets [12 -, 14]. Both AEMO and VicGrid have among their objectives the secure operation of the system, efficient development of transmission, active participation of governments and consumers, and energy resilience, understood as the capacity of the energy system to adjust to current and future physical risks related to climate change and the energy transition, and to manage the associated risks and opportunities [12, 15, 16]. In recent years, high renewable penetration has led to record instantaneous renewable shares of 85% in WEM and 76% in NEM, significantly displacing synchronous generation based on coal, gas, and hydropower and changing the technical and operational conditions for system resilience [17, 18].

AEMO prioritizes risks to energy resilience in line with the AASB S2 standard, considering probability of occurrence and the importance perceived by consumers [12]. Key risks include physical risks such as wildfires, cyclones, storms, and lightning, whose severity has increased, particularly in relation to extreme temperatures, humidity and, above all, wind strength [19]. This has affected regions with infrastructure not originally designed for such conditions, for example South Australia, which has experienced an increase in severe weather events [19]. The rapid introduction of renewable energy sources has also increased operational risks, as the power system has become more dependent on weather conditions; photovoltaic and wind plants have technical limits for temperature and wind, which can trigger large-scale disconnections [19]. Between 2024 and 2025, 22 non-credible contingencies were recorded, 7 of them were environmental, including the mass disconnection of transmission lines [19]. Recent extreme events, such as the 2021 incident in Queensland (loss of 3 GW of generation and forced disconnection of 2 GW of load) and the 2024 Moorabool event (transmission faults that disconnected all four units of Loy Yang A, with a total loss of 2,690 MW), illustrate how climate and infrastructure vulnerabilities interact in a system with increasing shares of inverter-based resources [17]. In 2025, the Australian Energy Market Commission amended Australia’s National Electricity Rules to introduce new resilience expenditure factors for distribution network service providers (DNSPs) and the Australian Energy Regulator (AER) to take into account when developing and assessing expenditure proposals. The Rules now specifically recognize the need for states and territories’ DNSPs to invest in resilience, and from the 2027-28 reporting year DNSPs will be required to report transparently on their levels of resilience investment.

The reliability of the Australian energy system is monitored by AEMO using the Unserved Energy (USE) standard, with an annual limit of 0.002% of energy not supplied, complemented by quality-of-supply indicators such as SAIFI and SAIDI [20]. In the 2023–2024 period, the average NEM customer experienced 1.58 interruptions and 393.8 minutes without supply [20]. A share of these interruptions is linked to scheduled outages, corresponding to 0.32 events and 99.3 minutes, which are necessary for maintenance and asset management [20]. However, climate-related disasters have become a major driver of vulnerability: their impact on outage duration (SAIDI) increased by 248% and on frequency (SAIFI) by 77% compared with 2022–2023, partly because non-credible events are excluded from efficiency calculations, which masks their true impact on the distribution network, where around 95% of interruptions originate [20].

From a policy and planning perspective, strategic resilience is embedded in AEMO’s Integrated System Plan (ISP), a local roadmap that coordinates the transition of the NEM towards net-zero emissions [21]. The Inputs, Assumptions and Scenarios Report (IASR) define scenarios such as Step Change, which are used to derive the Optimal Development Path (ODP) and identify the most resilient and cost-effective development trajectory for generation, storage, and networks [21, 22]. The modelling framework explicitly includes Supply Chain Constraints to capture the impact of logistical bottlenecks and labour availability on project timelines, testing how slower or more expensive deployment of new assets affects system adequacy and resilience [22]. In parallel, gas-fired generation is retained as a key flexibility resource to support the retirement of coal plants, whose network remediation costs are estimated at around USD 80 million per unit, reinforcing the robustness of the transition pathway against physical and economic uncertainties [22]. In this way, resilience is addressed through a combination of planning instruments (ISP, ODP), accounting and disclosure standards (AASB S2), and reliability indicators (USE, SAIDI, SAIFI), although the treatment of non-credible events in the regulatory framework remains a point of debate [12, 20, 22].

Specific financing mechanisms that directly address resilience in the energy sector were not identified, however, Australia has financing programs and agencies or organizations that allocate part of their budget to energy resilience matters. More broadly, the Disaster Ready Fund (DRF) is a program that provides, through the Australian Government, up to USD 670 million (AUD 1 billion) over five years for disaster resilience and risk reduction. This program supports projects to reduce disaster risk and strengthen community resilience to natural hazards. The DRF is administered by the federal National Emergency Management Agency (NEMA) in partnership with state and territory government agencies responsible for emergency management [23].

To address anticipated reliability gaps due to phased retirement of coal power, 62% of which will be offline by 2033, Australia is advancing a portfolio of incentive programs. These include the federal Capacity Investment Scheme, New South Wales' Electricity Infrastructure Roadmap and firming tenders, and Victoria's Renewable Energy Target Auction 2. These initiatives are coordinated with the federal Rewiring the Nation program, which provides finance for the build out of transmission infrastructure through the Clean Energy Finance Corporation. Together these various initiatives mitigate future reliability risks [24].

Also, the Australian Renewable Energy Agency (ARENA) has invested over USD 1.7 billion (AUD 2.61 billion) across 735 projects as of 2023 [25]. These range from solar PV and battery storage to hydrogen technologies and digital energy management systems. In August 2023, ARENA launched the USD 81 million (AUD 125 million) Regional Microgrids Program, with USD 49 million (AUD 75 million) specifically allocated to First Nations Community Microgrids. It also backed Horizon Power's trial of two long duration batteries in remote Western Australian microgrids [25]. Recognizing the growing climate risks, Australian governments are prioritizing resilient infrastructure through strategic investments and upgrades. For example, the Victorian Government's 'Resilient Infrastructure for a Safer Future' policy includes specific initiatives for energy networks to withstand climate impacts, such as undergrounding power lines and reinforcing transmission assets. It also aims to fast-track key energy infrastructure, expand energy storage (home, neighborhood, and grid-scale batteries), and support electrification and energy efficiency [26]. Institutional coordination is also improving through inter-agency collaborations, such as between the Department of Climate Change, Energy, the Environment, and Water (DCCEEW), AEMO, and the Clean Energy Finance Corporation (CEFC). These bodies jointly assess risks, provide funding, and shape local planning efforts.

A prominent example of a resilience-oriented project is the Waratah Super Battery (WSB), implemented under the System Integrity Protection Scheme (SIPS) [19, 22]. The WSB is designed as a "virtual transmission line" that increases the usable capacity of the existing network and provides a rapid-response buffer against non-credible contingencies by injecting up to 850 MW of power almost instantaneously [17, 27]. The project, which entered partial operation in 2025, demonstrates how large-scale Battery Energy Storage Systems (BESS) can enhance system security by allowing higher utilization of interconnectors while maintaining stability margins [19, 22, 27]. More broadly, AEMO considers that the integration of distributed BESS across the NEM has confirmed their operational value in the short and medium term, with modelling exercises showing that scenarios with widespread BESS deployment can keep interconnection flows within safe ranges compared with scenarios without storage, thereby strengthening the overall resilience of the Australian power system [19].

3.2 Brunei Darussalam

Brunei Darussalam's energy matrix is characterized by an almost complete dependence on fossil fuels, a condition widely recognized as one of its key regional factors in policy design and implementation. Electricity generation relies almost entirely on natural gas, with only a marginal contribution from solar photovoltaic energy, which makes the electricity sector the largest source of greenhouse gas emissions, accounting for 55.9% of regional emissions [28]. This rigid and weakly diversified structure is combined with strong growth in demand; between 2010 and 2018, subsidized fuel prices stimulated consumption and electricity generation increased by 14.3%, indicating the high sensitivity of energy use to price incentives [28]. The low level of diversification documented across regional and technical assessments amplifies the vulnerability of the energy system to international fuel price fluctuations and limits Brunei Darussalam's ability to strengthen energy security [28, 29].

The economy also faces major climate risks identified at the regional level, including floods, forest fires, strong winds, and landslides [28]. Floods are the most frequent natural hazard due to intense rainfall patterns, and variability associated with El Niño can trigger extended dry periods and forest fires, while extreme wind events and coastal erosion directly affect infrastructure, communities, and long-term spatial planning [30]. Brunei Darussalam has adopted several adaptation measures, such as integrated environmental management, long-term assessments of temperature and rainfall trends, and the inclusion of climate risk in land planning [28].

Regional resilience also relies on physical and institutional components. More than 50 kilometers of coastal defenses have been constructed to reduce storm surge impacts, saline intrusion, and coastal erosion, while the National Disaster Management Center coordinates prevention, preparedness, monitoring, and disaster response within the ASEAN AADMER regional framework [30]. Despite these efforts, both [28] and [30] show that the electricity sector is not addressed as an independent element within the regional resilience strategy, and references to system improvement or modernization appear only indirectly.

In the region, public funding linked to energy resilience mainly comes from the Twelfth National Development Plan (RKN12, 2024–2029) and the annual local budget. The RKN12 sets aside about USD 3.0 billion (BND 4.0 billion) for development and infrastructure projects between 2024 and 2029 [31]. For FY2025/2026, the government announced development spending of around USD 355 million (BND 480 million), showing a continued focus on infrastructure, including the energy sector [32]. Under this plan, investments in power generation and system upgrades are seen as key actions to support supply security and make the electricity system more resilient to climate and operational risks [31, 32]. These efforts are supported by Brunei Darussalam's National Adaptation Plan for Climate Change, which sets out a policy framework to protect critical infrastructure and improve recovery after climate-related events [33]. In addition, the World Bank's Doing Business 2020 reports very high electricity distribution reliability in the region, with SAIDI = 0.4 and SAIFI = 0.3, based on the "Getting Electricity" assessment, offering internationally comparable indicators even though they are not published regularly by the local utility [34].

From a technical perspective, Brunei generates 99.95% of its electricity from thermal sources based on natural gas and petroleum, with only 0.05% coming from solar photovoltaic installations, totaling 4269 GWh and 777.7 MW of installed capacity [29]. The scientific literature provides further insight into mitigation pathways. The study Sustainable energy towards air pollution and climate change mitigation evaluates life cycle greenhouse gas emissions, lifetime characteristics, and levelized costs of electricity for current and potential technologies, including natural gas, diesel, solar photovoltaic, hydro, and offshore wind. Based on optimization results, Brunei Darussalam could reduce its emissions by 10.3% by adjusting its generation mix toward appropriate renewable sources [29]. These findings align with Brunei Darussalam's international commitments under the Intended Nationally Determined Contribution submitted to COP21, which includes reducing total energy consumption by 63%by 2035, increasing the renewable share to 10%, reducing peak hour transport emissions by 40%, and maintaining forest cover at 55%as a natural carbon sink [35]. All these objectives are framed by the Energy White Paper, the local document that defines Brunei's energy vision toward 2035 and establishes strategies for improving energy efficiency, promoting diversification, reducing overall consumption, and expanding renewable energy deployment, forming the policy foundation for subsequent regional energy and climate actions [36].

3.3 Canada

Canada produces 4% of the world's primary energy, ranking sixth after India, with crude oil representing the largest contribution at 38%, while renewables represent 6%, primarily hydropower at 4%, from which Canada exports electricity to 132 economies, with 94% destined for the U.S.A [37]. In the electricity matrix specifically, hydropower consolidates its dominance at 57.4% of total generation in 2023, positioning it as the central element of the electricity supply and of export interdependence with the U.S. market [37]. The supervision and regulation of the local energy system involve the Canada Energy Regulator (CER) at the federal level and provincial regulatory entities, in coordination with Natural Resources Canada (NRCan) and Statistics Canada [37]. Climate risks have intensified and vary spatially: northern territories face accelerated thaw and permafrost destabilization, provinces such as Alberta and British Columbia are increasingly exposed to wildfires and large flood events, and coastal regions face storm surge intensification and sea-level rise [38]. In the context of critical energy assets, flooding has emerged as the costliest hazard due to the concentration of key energy infrastructure near river basins, aging assets, and substation exposure, while wildfires threaten approximately 40,000 km^2 of forested area and have directly affected electricity and oil and gas production, as evidenced in 2023 during the most destructive wildfire season on record [38].

Resilience standards are guided by the Canadian Standards Association (CSA), while reliability standards are mandatory under NERC regulations [39]. Given the provincial structure of the system, Ontario provides a representative case due to its demographic weight (39% of local population) and electricity demand (25.3% of local consumption) [37, 40]. Recent performance indicators report a Transmission SAIDI of 4.3 minutes per delivery point and a Distribution SAIDI of up to 7.7 hours per customer annually, exceeding the corporate threshold of 6.5 hours, primarily due to vegetation interference and climate-related external events such as severe flooding and wildfires, revealing structural vulnerabilities in local distribution networks [38, 39, 41]. In response to escalating physical risks, the federal government launched the Disaster Mitigation and Adaptation Fund (DMAF), committing CAD 3.8 billion through 2033 for energy-related resilience infrastructure, while the 2023 National Adaptation Strategy (NAS) and its Action Plan (GOCAAP) integrate climate-based decision-making into planning, including provisions for climate-informed building codes, hazard-based land use restrictions for energy-critical corridors, and mandatory disclosure of climate risk [38]. Additionally, the federal package of Investment Tax Credits (ITCs) supports clean electricity, carbon storage, and grid modernization, constituting a coordinated financial framework for transition and resilience [38].

In Canada, grid resilience financing seems to be primarily addressed through regulatory mechanisms rather than dedicated resilience funds. In the case of BC Hydro (British Columbia Hydropower and Energy Authority), restoration and resilience costs related to storms are managed through the Storm Variance Regulatory Account (SVRA), through a rate regulation accounting mechanism. BC Hydro forecasts costs related to storm according to historical averages and initially finances both resilience investments and restoration expenses through its own capital expenditures. Any deviations between forecasted and actual costs are deferred and subsequently recovered from ratepayers over future tariff periods, typically within two to three years [42].

Programs such as the Smart Renewables and Electrification Pathways Program (SREPs), launched in 2021, directly fund resilient infrastructure deployment. The 147 supported projects include 75 that will deliver 2,700 MW of renewable generation and 2,100 MWh of storage capacity [43]. Federal investments also include a CAD 500 million (USD 346.2 million) loan guarantee for the Maritime Link and support through the Canada Infrastructure Bank (CIB) for Nova Scotia's Green Choice program [43]. Major long-term grid investments reflect Canada's prioritization of reliable and expanded grid capacity, like BC Hydro's 10-year plan with a CAD 36 billion budget (USD 26.3 billion) and Hydro-Québec's up to CAD 185 billion (USD 128.09 billion) allocation [44].

Among Canada's most relevant resilience-oriented outcomes is the structural transformation of Ontario's electricity mix, marked by the progressive coal phase-out initiated in 2001, resulting in a 62% reduction in electricity-sector emissions between 2000 and 2023 [37]. Beyond its decarbonization value, this shift strengthened long-term operational stability by reducing dependence on volatile fossil supply chains and increasing system modularity for extreme-event recovery. Similarly, the CANDU refurbishment program, identified as Canada's largest infrastructure initiative under execution, ensures secure baseload availability beyond 2050, preventing approximately 50 million tons of CO_2 annually while reinforcing supply continuity during extreme climate events, given that nuclear output remains insulated from hydrological variability and wildfire-related disruptions that affect transmission corridors [37]. Grid expansion, including the Chatham to Lakeshore Transmission Line (commissioned one year ahead of schedule and below cost) and participation in the East-West Tie line, demonstrates enhanced recovery capacity, redundancy, inter-provincial balancing, and increased corridor robustness during meteorological contingencies [39, 41]. In this way, Canada's success cases contribute not only to diversification and decarbonization objectives, but also to measurable resilience gains: stronger baseload availability during disturbances, reduced dependence on fossil-exposed supply chains, improved interconnection redundancy, and accelerated restoration capacity during wildfire and flood-triggered disruptions.

3.4 Chile

Chile's National Electric System (SEN) is a single interconnected grid of approximately 3,100 km that supplies more than 97% of the population, supported by extensive long-distance transmission corridors and regional distribution systems [45]. Over the last decade, Chile has experienced an accelerated energy transition, with renewable electricity representing around 63% of total generation in 2023 and close to 68% in 2024, while thermal participation continued to decline [46]. Although this transition has positioned Chile among the economies with the highest renewable penetration in APEC, system stability still depends on fossil backup plants and presents structural challenges associated with drought, extreme weather events and distribution-system performance [46].

The institutional and regulatory framework for energy resilience operates across climate and energy planning instruments. The Framework Law on Climate Change No. 21.455 establishes binding mitigation and adaptation obligations and mandates sectoral plans, including for energy, to achieve and maintain carbon neutrality by 2050 [47]. Complementarily, the National Energy Policy (2022) sets a strategic vision for 2050 that explicitly includes "security and resilience of the energy system" as a core pillar In this context, Chile defines a resilient system as one that has the capacity to anticipate, resist, absorb, adapt to, and recover from the effects of an event in a comprehensive, timely, and effective manner, while ensuring the preservation, restoration, or improvement of its basic structures and functions [48]. The Sectoral Plan for Mitigation and Adaptation to Climate Change in the Energy Sector (PSMA Energía), prepared by the Ministry of Energy, is organized around four strategic axes: productive reconversion, resilient and enabling infrastructure, transition fuels and sustainable financing, and includes a detailed diagnosis of climate risks and adaptation priorities for energy facilities (generation, transmission and distribution), consolidating the current policy framework for resilience [49]. Despite these advances, the General Electricity Services Law (LGSE) does not define resilience explicitly, and references remain limited to specific regulations (such as transmission planning and risk management provisions) highlighting a regulatory gap that has been identified in technical diagnostics prepared by the Ministry of Energy with GIZ [50].

Climate risks affecting the SEN are dominated by the prolonged megadrought, which has reduced water availability by nearly 30% in central regions since 2010 and placed strong constraints on hydropower output [51]. According to PSMA Energía, increased heat waves, flooding, extreme rainfall and forest fires constitute converging climate pressures that elevate peak demand, damage assets and increase interruption risks, reinforcing the need to incorporate climate criteria into system planning, infrastructure standards and emergency coordination [49]. These risks have been confirmed by recent episodes of heat and wildfires in the south-central corridor, which have triggered emergency declarations and accelerated vulnerability assessments for critical assets [50,52].

At the operational level, distribution reliability remains the most pronounced bottleneck for resilience. Although SAIDI fell from 14.52 hours in 2022 to 13.58 hours in 2023, users continue to face interruption durations far above OECD benchmarks [53]. Studies based on SEC statistics show that while system averages have improved significantly over the past decade, the dispersion of outages remains extreme, with some communes experiencing up to 10 times the local average, underscoring persistent weaknesses in low- and medium-voltage networks and vegetation management, especially in peri-urban and rural zones [54].

To advance implementation, Chile has undertaken targeted assessments to integrate climate adaptation into infrastructure development. A 2023 study commissioned by the Ministry of Energy and GIZ on climate-resilient energy infrastructure identifies vulnerabilities by technology and climatic zone, evaluating impacts on substations, transmission towers and thermal plants under progressive climate scenarios, and proposes risk-screening methodologies and engineering measures such as flood-elevation criteria, thermal-stress analysis and redesign of asset-maintenance cycles [50]. These insights complement the PSMA diagnosis and local resilience planning under the National Energy Policy (2022). In parallel, PSMA Energía explicitly mandates the incorporation of climate risk and vulnerability criteria into the Long-Term Energy Planning (PELP) process, in line with the institutional framework established by the Climate Change Framework Law. In particular, Adaptation Measure A4-A establishes the development of guidelines and procedures to integrate climate risk assessments into PELP, with the objective that upcoming planning cycles adopt updated methodologies that systematically account for climate resilience considerations [55] and are operationalized through the local long-term energy planning instrument [56].

In regulatory terms, resilience is supported by security-of-supply standards and oversight mechanisms. Law No. 18.410 mandates SEC supervision of compliance with quality, safety and continuity requirements for electricity services, while the Technical Security and Quality Standard (NTSyCS) define operational adequacy criteria for the regional grid and updated protection and contingency protocols [57,59]. Recent events illustrate the tension between institutional maturity and infrastructure gaps: in 2024, SEC imposed a fine of nearly USD 4 million on Enel for failures during extreme rains, and in 2025 levied another sanction of approximately USD 19 million for non-compliance associated with prolonged interruptions [60]. Conversely, the February 2025 economy-wide blackout, originating from an unscheduled disconnection in the 500 kV system, exposed structural vulnerabilities in transmission planning and protection coordination, prompting reforms and audits to reinforce systemic security [61].

In terms of funding, energy resilience in Chile is supported by both public and private investment, including public–private partnerships, with most public funding coming from the local budget. Official planning and regulatory documents show that, over the past decade, Chile has invested several billion U.S. dollars in expanding electricity transmission, reinforcing the grid, and building other infrastructure related to resilience. These investments include key projects to strengthen the system and maintain reliable electricity supply in regions exposed to natural hazards [48, 62]. In addition to direct investment, Chile's climate strategy and related policy documents estimate that the annual cost of not acting on climate change could exceed USD 4 billion by 2050. Although this is not a specific budget allocation, it highlights the scale of the potential impacts and reinforces the case for investing in energy system resilience [63, 64].

In synthesis, Chile exhibits an advanced planning and legal architecture for energy resilience, anchored in the Climate Change Framework Law, PSMA Energía, the National Energy Policy (2022), SEC enforcement and updated technical standards, yet remains exposed to the compounded effects of drought, more frequent extreme events, and aging distribution and transmission segments. This positions Chile in an intermediate stage: with normative and institutional tools largely in place but requiring accelerated implementation, infrastructure modernization, distribution-system reinforcement and clearer incorporation of resilience in core sector regulations to ensure stable operation under intensifying climate and operational stress [60,61,55,65].

3.5 People's Republic of China

People's Republic of China is simultaneously exposed to floods, cyclones, earthquakes, droughts, extreme wind events, heat waves and wildfires, making it one of the economies with the highest concentration of climate-related threats to its electricity network, including transmission lines, substations, and large hydropower assets [66]. These hazards generate outages, physical damage and hydroelectric reductions during dry years, which explains the strategic emphasis placed on reinforcing the resilience of thermal, hydro, wind and solar power plants and protecting transmission infrastructure while strengthening emergency response and rapid reconstruction capacity across the system [66]. Structurally, this economy operates the world's largest power system, with total generation reaching 8849 TWh in 2022 [67], and although the generation mix has diversified (reducing coal from 81% in 2007 to 65.5% in 2017) coal remains the dominant source of electricity, accounting for 40% of local emissions and 11.1% of global emissions [68]. At the same time, the People's Republic of China is the world leader in installed wind and solar capacity, but rapid expansion has generated high curtailment in several regions, revealing constraints in system flexibility and the lag of transmission modernization relative to renewable deployment [68]. These structural challenges became evident during the extreme heat and low hydrology events of 2021–2022, when coal price volatility and regional capacity shortages increased stress on the system and shifted local policy attention toward energy security and resilience as a dual strategic axis [67].

Although no financing mechanisms that directly consider resilience in the energy sector were identified in the People's Republic of China, the economy is reinforcing the resilience and reliability of its energy infrastructure through major strategic investments and government-led planning. China's State Grid Corporation of China, in coordination with the National Energy Administration and the National Development and Reform Commission, has accelerated investment in ultra-high-voltage transmission, smart grid technologies, digitalization and real-time monitoring systems, with annual grid investment exceeding RMB 600 billion (USD 84 billion) and cumulative energy sector spending forecast into the hundreds of billions of dollars as part of its energy transition and infrastructure modernization agenda [69, 70]. These efforts also include diversifying its energy mix by significantly expanding renewable capacity, adding 297.6 GW in 2023, and improving interconnections through microgrids and cooperative planning [71]. These infrastructure upgrades are supported by institutional strategies embedded in the 14th Five-Year Plan, which targets carbon peaking by 2030 and neutrality by 2060 [72].

Regional differentiation of risks is significant. Arid and semi-arid provinces such as Xinjiang, Ningxia, Gansu and Inner Mongolia face recurrent droughts, severe water stress and limited hydrological support for electricity generation, requiring integrated adaptation strategies including water–energy–food nexus planning, smart irrigation and diversification of heat-tolerant crop varieties to ensure long-term socioeconomic and energy stability [73]. Social perceptions are also relevant in resilience planning: local surveys demonstrate that support for renewables and electrification correlates with public concern about climate change and is reinforced by China's commitment to carbon neutrality by 2060, which guides long-term energy policy design and transition timelines [74]. Despite increasing diversification, this economy has continued dependence on coal during the transition necessitates carefully managed decarbonization to avoid abrupt supply risks. Recommended measures include strengthening storage and grid flexibility, accelerating renewables, avoiding abrupt fossil reductions, prioritizing wind expansion for security benefits, and reducing oil import dependence to lessen exposure to price volatility and geopolitical uncertainty [75].

In terms of governance, the People’s Republic of China has historically prioritized economic efficiency in its power system expansion. However, recent policy orientation increasingly integrates climate adaptation and risk management. In June 2022, China’s National Climate Change Adaptation Strategy 2035 was issued jointly by 17 ministries and government bodies, outlining actions to strengthen climate change monitoring, early warning systems, and climate risk assessment across sectors and regions. The Strategy calls for improved forecasting, observation networks and risk management frameworks to enhance resilience to climate impacts, including extreme weather and natural hazards that affect critical infrastructure such as energy systems [76-, 78]. This demonstrates the existence of regional-level regulation that recognizes resilience not only as a mitigation co-benefit but as a dedicated policy domain linked directly to disaster management and climate exposure [76]. Complementarily, China has increased regional coordination in electricity exchange to expand balancing areas and reduce reserve requirements across climate zones, improving resilience by addressing renewable variability imbalances and lowering curtailment [67].

Although not all resilience measures translate into visible infrastructure outcomes, one of the most relevant cases demonstrating resilience-oriented system strengthening is the expansion of interregional power coordination, which has allowed seasonal and climate-driven balancing between hydro-dominant regions and those exposed to drought or peak heat conditions [67]. China’s leadership in renewable deployment (despite curtailment constraints) also represents a resilience advantage when combined with new storage, as it reduces exposure to fossil price shocks, supports autonomy and facilitates recovery from climate-induced outages through modular deployment and rapid re-dispatch capacity [67,68]. In 2019, People´s Republic of China recorded a SAIDI of 13.72 hours per household per year, which is significantly higher than the average of 1.23 hours observed among other benchmarks reported in [79]. In sum, the current resilience efforts combine structural diversification, coordination of large balancing regions, climate risk monitoring, and explicit regulatory frameworks under the 2035 Adaptation Strategy, reflecting a transition from a purely efficiency-oriented expansion to an energy security and resilience paradigm explicitly shaped by climate hazards.

3.6 Hong Kong, China

The Government of Hong Kong, China has long maintained a policy aimed at ensuring that the electricity demand of the community is met safely, reliably, efficiently and at reasonable prices, while minimizing the environmental impact of electricity generation. Hong Kong, China enjoys one of the most reliable electricity supplies globally, with the tariffs remaining at an affordable level. The Hong Kong, China’s

Climate Action Plan 2050 has set “net-zero electricity generation” as one of the major decarbonization strategies. In this connection, the share of coal in Hong Kong, China’s overall fuel mix for electricity generation has been reduced from about half in 2015 to about one-fifth at present, while the share of natural gas has significantly increased from about a quarter in 2015 to more than half. In 2024, the fuel mix for electricity generation consists of 55.5% natural gas, 24.5% nuclear and renewable electricity imported from Chinese Mainland, and 20% coal. Regarding renewable energy, the target is to increase its share in the fuel mix for electricity generation to 10% by 2035, and further increase it to 15% subsequently [80]. System operation and planning are concentrated in two main electricity companies which, under Hong Kong, China’s regulatory framework, have maintained a supply reliability index of 99.99% for decades [81]. In 2023, the power system recorded a SAIDI of 0.057 and a SAIFI of 0.103, placing Hong Kong, China among the most reliable systems globally [81, 82].

Climate change has already led to higher average temperatures, more frequent intense rainfall and rising sea levels, which increase flood risk, storm surge exposure, and the likelihood of weather-related infrastructure stress [83]. In response, the Government released Hong Kong, China’s Climate Action Plan 2050, built around four pillars: net-zero electricity generation, energy saving and green buildings, green transport, and waste reduction [83]. Given that electricity generation accounts for nearly two-thirds of Hong Kong, China’s carbon emissions, the plan places particular emphasis on transforming the power sector, including phasing out coal for daily generation by 2035, raising the renewable share to 7.5–10% by 2035 and to around 15% thereafter through local projects, regional cooperation and joint ventures, and increasing the share of zero-carbon electricity to 60–70% before 2035 [83]. These measures, combined with the existing reliability indicators (SAIDI, SAIFI) and long-standing performance targets, form the backbone of the territory’s strategy to address both decarbonization and resilience, by reducing exposure to fossil fuel price volatility and strengthening the capacity of the system to cope with climate-related shocks [82, 83].

At the level of concrete resilience initiatives, CLP Power has introduced Grid-V, an intelligent energy management and monitoring system designed explicitly to strengthen grid resilience against climate risks [84]. Grid-V integrates around 3,000 data points and cameras to provide continuous monitoring of critical facilities and incorporates an artificial intelligence platform capable of analyzing environmental risks, detecting anomalies and identifying potential threats such as fires or foreign objects that could compromise power plant operation [84]. The company plans to expand the coverage of Grid-V and enhance its analytical capabilities, positioning it as a key tool for anticipatory risk management and faster response during extreme weather events [84,85].

These technology and infrastructure initiatives are supported by a broader climate policy and investment framework. Hong Kong, China’s Climate Action Plan 2050 indicates that the government plans to invest around USD 31.0 billion (HKD 240 billion) over the next 15–20 years in climate mitigation and adaptation, including measures to strengthen the resilience of critical infrastructure against extreme weather events [86]. In Hong Kong, China, funding related to energy resilience is not provided through a single standalone public budget. Instead, it relies on a mix of public and private efforts and is primarily delivered through regulated capital investment by electricity utilities under the Scheme of Control Agreements. These agreements require government-approved, multi-year development plans for expanding and reinforcing the power system [87]. For the 2024–2028 planning period, approved development plans include capital expenditures of about USD 9.9 billion (HKD 52.9 billion) for CLP Power Hong Kong and USD 4.1 billion (HKD 22.0 billion) for Hongkong Electric Company. These investments focus on generation capacity, strengthening transmission and distribution networks, and improving system redundancy [88]. Assessments by CLP Power Hong Kong Limited show that long-term investments and system improvements helped maintain an exceptionally high electricity supply reliability rate of 99.999 % in 2024, and that the company is implementing multi-pronged resilience measures to strengthen the ability of the grid to withstand and recover from external disruptions, including extreme weather events. [89].

3.7 Indonesia

Indonesia is an archipelagic economy with a fragmented electrical system distributed across multiple islands, where the state-owned company PLN dominates generation, transmission and distribution, and where public policy assumes that electricity supply is under state control and should be oriented towards the "maximum welfare of the people" [90, 91]. The Electricity Law No. 30/2009 assigns to the central and regional governments the responsibility to formulate policies, regulate, supervise and develop comprehensive electricity plans in line with the National Energy Policy (KEN), promoting the optimal use of energy resources and prioritizing new and renewable sources to ensure a sustainable and secure supply [90, 92]. In quantitative terms, Indonesia has achieved a high regional electrification rate and, according to the IEA policy review, has steadily expanded generation capacity and grid infrastructure to meet growing demand, although gaps in supply quality and reliability persist in some regions outside Java [91]. The share of renewable energy in the electricity mix remains relatively low (slightly above 10% in 2024), which makes an accelerated change in the generation mix necessary to meet the targets of the KEN and the enhanced NDC (ENDC) [91, 93]. The KEN, approved under Government Regulation No. 79/2014, sets goals such as increasing the share of renewables to at least 23% in 2025 and 31% in 2050, reducing the weight of oil and improving the reliability of production, transport and distribution systems, explicitly linking security of supply with the resilience of the local energy system [92, 93].

As for reliability indicators in Indonesia, according to the Director General of Electricity of the Ministry of Energy in 2022, the values obtained for this year (compared to previous years) showed improvement and even managed to meet the target. The target set for 2021 was ten hours per customer per year, and in 2022, six hours per customer was achieved. While the SAIFI was four interruptions per customer per year, for comparison purposes, the SAIFI value in 2020 was 9.25 times per customer per year [94].

The main risks to Indonesia's energy system arise from its high exposure to natural disasters (earthquakes, tsunamis, floods) and from the large distances between consumption centers and primary resources, which complicate network expansion and increase the cost of supplying remote islands [91, 95]. These structural vulnerabilities are compounded by a historical dependence on coal and other fossil fuels, which exposes the system to price shocks and makes it more difficult to align energy development with climate commitments [91, 96]. In its enhanced Nationally Determined Contribution (NDC) and National Adaptation Plan (NAP), Indonesia explicitly identifies resilience in food, water and energy as a pillar for building "archipelagic climate resilience", integrating mitigation, adaptation and disaster risk reduction into development and infrastructure planning, including the electricity sector [95, 97, 98]. Cross-cuttingly, Disaster Management Law No. 24/2007 requires the integration of disaster risk into development planning and establishes the State's responsibility to protect and rapidly restore essential public services, including energy, anchoring power system resilience within the broader local risk management framework [98].

For Indonesia, a dedicated formal financing mechanism for energy resilience was not clearly identified. However, it does have financing programs that address investment aspects related to resilience, such as energy transition, risk preparedness, and climate funds. Policy frameworks such as the Just Energy Transition Partnership (JETP) allocated USD 20 billion to retire coal plants and fund clean alternatives [99]. Perusahaan Listrik Negara (PLN) investments in smart metering and grid automation support these goals. Infrastructure resilience includes elevating substations and decentralizing grids to operate autonomously when disrupted [100].

From a governance and planning perspective, the main policies and instruments are structured around the KEN and the National Energy General Plan (RUEN), established by Presidential Regulation No. 22/2017 [92, 93]. The RUEN acts as a roadmap to 2050 and a mandatory reference for regional energy planning, including the National Electricity General Plan (RUKN) and PLN's business plans (RUPTL); it sets efficiency targets (such as reducing energy intensity by 1% annually) and renewable energy targets, and is conceived as an instrument to achieve energy security and resilience across all provinces [91, 93]. In this way, resilience is addressed both through long-term energy planning (KEN, RUEN, RUKN, RUPTL) and through disaster risk governance (Disaster Management Law, NAP), which together define the institutional architecture for integrating climate and disaster risks into energy system development [91-95, 98].

As concrete and emerging success case, the RUPTL 2021–2030, known as "Green RUPTL", approved by the Ministry of Energy and Mineral Resources, foresees around USD 90 billion in investments in generation, transmission and distribution to expand and strengthen the grid, improve supply quality and integrate distributed energy resources such as rooftop solar PV [96, 101]. The Indonesia Electricity Network Transformation (I-ENET) program, supported by the World Bank, finances modernization of the distribution network and the adoption of smart grid technologies (SCADA/ADMS, advanced metering) in Java, Madura and Bali, with the explicit objective of increasing grid capacity and reliability and improving responsiveness to disturbances [101]. Recent analyses show that, under the RUPTL 2021–2030, Indonesia plans to add more than 20 GW of new renewable capacity, and that the draft new RUPTL 2025–2034 aims for around 70% of the planned 71 GW of new capacity to be renewable, raising the renewable share to close to 35% in 2034 and reducing reliance on coal [96, 102]. Taken together, these measures illustrate how Indonesia is beginning to connect energy transition targets with resilience objectives, using planning instruments, disaster risk regulations and large-scale investment options to strengthen security of supply and the ability of its archipelagic power system to cope with climate and market shocks [92–97, 99–102].

3.8 Japan

Japan has a highly developed but distinctive electricity system, historically segmented into two large regions operating at different frequencies (50 Hz and 60 Hz) and heavily dependent on thermal generation and imported fuels, supplemented by nuclear and renewable energy sources [103,104]. The Basic Act on Energy Policy (Act No. 71 of 2002) sets the overall principles of energy policy under the S+3E framework, safety as a prerequisite, plus energy security, economic efficiency and environmental compatibility and requires the government to formulate and periodically revise a Basic (Strategic) Energy Plan that guides the evolution of the power mix and infrastructure [103,105]. Within this framework, Japan's power system has progressively integrated higher shares of renewables while maintaining a significant role for nuclear, but the system remains structurally exposed to external fuel markets and must balance decarbonization goals with security of supply [103,106].

The main threats to Japan's energy resilience stem from its extreme exposure to earthquakes, tsunamis, typhoons and floods, combined with a high concentration of population, infrastructure and demand in coastal zones and a strong dependence on imported fuels for power generation [104,107,108]. The 2011 Great East Japan Earthquake, the subsequent tsunami and the Fukushima Daiichi nuclear accident marked a turning point in energy, safety and disaster management policy, reinforcing the notion of "local resilience" as a guiding concept [107-109]. The Basic Act on Disaster Management and the Basic Disaster Management Plan explicitly identify electricity and other energy carriers as critical "lifelines" that must be protected and restored rapidly in the event of large-scale disasters, while the Fundamental Plan for National Resilience sets objectives and measures to strengthen infrastructure, including energy systems against low-probability, high-impact events such as massive earthquakes and typhoons [107-110]. In climate policy, the Long-Term Strategy under the Paris Agreement and the National Climate Change Adaptation Plan call for building a "strong but flexible nation" in the face of climate change, recognizing energy and transport infrastructure as priority sectors for adaptation and risk reduction [111,112]. In quantitative and planning terms, the 6th Strategic Energy Plan approved in 2021 targets a 2030 electricity mix of 36–38% renewables and 20–22% nuclear, reducing the share of fossil fuels and positioning renewables as the "main power source," while Japan's long-term target is to achieve carbon neutrality by 2050 and, in draft discussions, to reach around 40–50% renewables and about 20% nuclear by 2040 [103,106]. Energy resilience policies combine market reform, security-of-supply instruments, and disaster management. Since 2015, Japan has fully liberalized the retail market, legally unbundled transmission and distribution, and created the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) to coordinate system operation and grid planning at local scale, which is crucial for sharing reserves and supporting areas affected by extreme events [104,113]. In 2020, the Act for Establishing Energy Supply Resilience amended the Electricity Business Act and related legislation to "ensure a resilient and sustainable electricity supply system," requiring transmission and distribution operators to prepare disaster cooperation plans and strengthening OCCTO's role in interconnection planning and coordinated emergency response [114]. Analyses by the IEA and the World Bank highlight concrete measures such as the use of OCCTO to manage interregional power transfers during scarcity, investments in reinforcing and undergrounding power lines in typhoon-prone urban areas, and the development of local microgrids and decentralized solutions to secure supply for hospitals, shelters and other critical facilities during emergencies [104,115]. The National Resilience Plan and climate adaptation plans also promote updated design standards, vulnerability assessments of energy assets and the integration of flood and landslide risks into the siting and planning of new infrastructure [107,111,112].

In this context, funding related to energy resilience mainly comes from local disaster management, infrastructure, and energy policy programs [116], rather than from a single dedicated resilience fund. After major natural disasters, especially the 2011 Great East Japan Earthquake, the government has committed large public resources to disaster prevention, risk reduction, and infrastructure strengthening. These efforts are supported by ongoing annual budget allocations for public works and energy-related spending under Japan's local public finance framework [117]. Official reports show that more than USD 150 billion (over JPY 20 trillion) has been invested over the past decade in disaster-related measures and infrastructure upgrades, including critical energy systems such as power grids and fuel supply facilities [116]. At the sector level, Japan's Strategic Energy Plan 2025 highlights grid reinforcement, energy supply diversification, and system modernization as key actions to help the energy system withstand major disruptions, recover quickly, and become stronger over time [118]. Electricity supply reliability in Japan is tracked and published each year by OCCTO. The Report on the Quality of Electricity Supply for fiscal year 2022 shows economy-wide SAIFI values of 0.16 interruptions per customer and SAIDI values of 25 minutes per customer, meaning that outages are infrequent and usually short [119]. While these indicators worsened slightly compared with the previous year due to severe weather, especially Typhoon Nanmadol, overall reliability remains high by international standards. This performance reflects long-term investment in grid strengthening, disaster preparedness, and system redundancy, helping Japan maintain a stable power supply and recover quickly from disruptions.

Overall, Japan conceives energy resilience as part of an integrated regional resilience strategy, in which decisions on the power mix, decarbonization trajectory and security of supply are taken under the S+3E framework and systematically coordinated with disaster risk management and climate change adaptation policies [103,104,111,114].

3.9 Republic of Korea

The Republic of Korea's energy system operates under the geopolitical condition of an "energy island," with no continental interconnections and a critical dependence on imports, which represented 93.7% of Total Primary Energy Supply (TPES) in September 2025, dominated by oil (37%), coal (28.4%) and LNG [120]. Sector governance, traditionally led by the Ministry of Trade, Industry and Energy (MOTIE) and the state-owned utility KEPCO, is undergoing strategic restructuring through the creation of a new Control Tower composed of the Ministry of Climate Change and Energy and a Presidential Commission in charge of steering the Carbon Neutrality 2050 agenda [121]. At the system level, the grid is transitioning from a thermal–nuclear base towards a more resilient infrastructure, with the explicit objective of structurally decoupling economic growth from energy consumption while meeting the growing electricity demand of advanced industries and RE100-type commitments [121].

The climate risk landscape is severe, with estimates suggesting potential economic losses of around 3.73% of GDP by 2050 under high-emission scenarios [122]. Given the Republic of Korea's strategic reliance on nuclear power, operational resilience faces direct physical threats that challenge historical design assumptions, including degradation of electrical insulation by saline deposition from typhoons, external flooding of essential facilities due to intense rainfall, and the blockage of cooling water intake systems by marine organisms exacerbated by sea warming, which affects ultimate heat dissipation [123]. In addition, the growing frequency of wildfires poses a threat to off-site power supply, increasing the risk of transmission line damage and cascading failures [123]. A key concern for energy resilience is systemic vulnerability: failures in non-critical (non-safety grade) components can propagate toward safety-grade structures, systems and components (SSCs), endangering the stability of base-load infrastructure [123].

In terms of quantitative indicators, Republic of Korea's power system has historically exhibited high reliability, with a SAIDI of 0.04 hours in 2020 (comparable to Japanese levels and better than most OECD economies) [124]. However, system adequacy is under pressure during summer peaks: for August 2024, projections place the reserve margin at a tight 8.5%, leaving a safety buffer of just 8,245 MW, with available capacity of 105 GW against a maximum demand of 97 GW [120]. This reinforces the idea that resilience depends not only on internal robustness but also on the uninterrupted functioning of global fuel supply chains, given the import dependence described above [122]. Strategically, resilience policies are articulated through the Basic Plan for Electricity Supply and Demand, whose central objective is to guide structural changes toward carbon neutrality by 2050 [121]. Recent political signals mark a shift toward a dual-track strategy that promotes parallel development of renewable energy and nuclear power, redefining nuclear as a fundamental pillar of resilience [121]. This approach entails, for example, a projected 5.3% increase in nuclear generation in 2024 through the commissioning of new plants to guarantee supply stability vis-à-vis renewable intermittency and to support the electricity needs of AI, semiconductor manufacturing and other advanced industries [124,125].

Republic of Korea implements resilience financing through the Korea Green, Resilient and Innovative Development (K-GRID) initiative. While K-GRID explicitly targets resilient energy and infrastructure systems, it is primarily designed as an international cooperation and development finance mechanism rather than a domestic energy resilience fund. The Government of Korea committed USD 30 million to the K-GRID program, comprising USD 10 million in blended finance and USD 20 million in advisory services. This budget supports International Finance Corporation (IFC) projects aimed at reducing greenhouse gas emissions and facilitating the acquisition and deployment of technologies that contribute to climate mitigation and system resilience [126]. Additionally, Ulsan's Hydrogen City project, part of the region's hydrogen pilot program, will expand hydrogen infrastructure with KRW 29.5 billion (USD 21.5 million) over four years. A real-time safety monitoring system will oversee hydrogen production, transport, and use via the Yuldong District Hydrogen Integrated Safety Management Center. This initiative will enhance safety and system reliability for Korea's growing hydrogen economy [127].

As a prominent success case in resilience-oriented innovation, Jeju Island has been designated a strategic hub for offshore wind development and grid modernization [121]. Jeju functions as a testbed for an "electrical island," where the integration of grid stability technologies is validated under real operating conditions, including the expansion of HVDC systems for long-distance, high-capacity transmission and the deployment of BESS to manage renewable intermittency and maintain system stability [121]. The operational experience accumulated in Jeju underpins the regional plan to build a U-shaped offshore "Energy Highway" by 2030 along the west coast and by 2040 around the entire peninsula, a megaproject conceived to replicate this robust interconnection model at regional scale, enabling large-scale transport of clean electricity from coastal generation hubs to inland industrial centers and enhancing overall security of supply and resilience in a decarbonizing power system [121].

3.10 Malaysia

Malaysia's energy system remains heavily shaped by a long-standing reliance on fossil fuels: in 2020, natural gas accounted for 42.4% of total primary energy supply, followed by petroleum products at 27.3% and coal at 26.4%, while renewables contributed only 3.9% [128]. This structure is reflected in the regional emissions profile, where the energy sector was responsible for 78.5% of total greenhouse gas emissions in 2019, underscoring the central role of energy systems in Malaysia's mitigation and resilience pathways [128]. Historically, the power sector operated as a vertically integrated monopoly, but progressive liberalization introduced independent power producers and market-based reforms aimed at improving efficiency, attracting investment and maintaining reliable electricity supply [128]. These changes are consistent with the broader reform trajectory identified in the Electricity Supply Industry (ESI) reform analysis, which highlights the move toward a more competitive electricity market with clearer regulatory rules, tariff reforms and expanded third-party access as a foundation for a more flexible and resilient power system [129].

At the same time, Malaysia faces significant climate risks that directly affect energy infrastructure and long-term development. The Malaysia Adaptation Index identifies floods, sea-level rise, river-flow extremes and coastal hazards as major threats with cross-sector implications for infrastructure, urban systems and energy facilities [130]. Projected increases in river discharge and more intense rainfall events raise the probability of dam failures and downstream inundation, while coastal areas are increasingly exposed to erosion and marine flooding under future climate scenarios [130]. These hazards threaten substations, transmission corridors, hydropower assets and urban load centers, making adaptation a core dimension of energy resilience. The Adaptation Index emphasizes long-term climate modelling, integrated land-use planning, vulnerability mapping and investments in flood-mitigation infrastructure as key measures that, while not exclusive to the energy sector, indirectly strengthen the robustness of Malaysia’s electricity system against climate shocks [130].

Regionally, Malaysia’s participation in the ASEAN Power Grid adds another layer to its resilience and security considerations. The LTMS-PIP report describes Malaysia’s dual role as importer and potential exporter in multilateral power-trading arrangements, noting that climate-induced hydropower variability in neighboring regions such as Laos and extreme weather across the region can directly disrupt cross-border electricity flows [131]. To address these risks, the report stresses the need for resilient regional interconnections capable of withstanding heatwaves, storms and hydrological fluctuations, as well as harmonized rules for wheeling, system operation and market coordination [131]. These regional interdependencies intersect with Malaysia’s domestic energy transition goals and underscore the importance of grid flexibility, interconnector robustness and coordinated regional planning.

The National Energy Transition Roadmap (NETR) consolidates these local and regional pressures into a long-term strategy that explicitly links decarbonization, security of supply and resilience [128]. NETR frames the transition as a structural shift toward cleaner energy sources, accelerated electrification and reduced carbon intensity, underpinned by a commitment to cut carbon intensity by 45% by 2030 relative to 2005 [128]. It sets out a broad package of actions, including scaling energy efficiency, electrifying transport, expanding hydrogen and bioenergy, deploying CCUS and phasing out coal from the power mix. Under the Reference Transition (RT) pathway, the share of renewables in power generation is projected to increase from 4% in 2023 to 22% by 2050, while coal falls to near zero and natural gas remains a key transitional fuel, accounting for around 56% of TPES by 2050 [128]. In parallel, NETR proposes structural changes to the Malaysian Electricity Supply Industry (MESI), including tariff restructuring to reflect true system costs, smart-grid deployment, expanded access to networks to foster competition in gas and electricity markets, and the development of an electricity exchange to facilitate renewable energy trade [128]. These reforms are framed not only as decarbonization tools but also as mechanisms to enhance resilience by diversifying suppliers, improving operational flexibility, enabling higher renewable penetration and reducing vulnerability to future coal or gas supply constraints [81,128]

These policy commitments and structural reforms are underpinned by public investment frameworks that channel resources toward energy security, climate adaptation, and system resilience. Funding related to energy resilience in Malaysia mainly comes from local development plans and annual federal budgets, rather than from a single dedicated resilience fund [132]. Under the Twelfth Malaysia Plan, the government directs significant resources to infrastructure development, climate adaptation, and energy security, including actions to strengthen electricity networks and improve system reliability. The plan sets aside about USD 95 billion (MYR 400 billion) in total development spending over the plan period, with energy infrastructure, grid upgrades, and climate-resilient assets listed as priority areas [132]. Alongside this, Malaysia’s annual federal budgets have increased funding for flood mitigation, disaster risk reduction, and the protection of critical infrastructure. Across recent budget cycles, more than USD 3.3 billion (MYR 15 billion) has been committed to flood control and other resilience-related projects [133,134]. At the sector level, official energy statistics point to continued investment by the local utility to reinforce transmission and distribution networks, improve operational readiness, and support faster system recovery after extreme weather, while also strengthening the system over the long term [135]. Electricity distribution reliability in Malaysia is reported by the Energy Commission through the Malaysia Energy Statistics Handbook. The 2023 edition shows that SAIDI values in Peninsular Malaysia are generally below one hour per customer per year, while SAIFI values remain below one interruption per customer per year, meaning that power outages are usually short and infrequent. The data also highlight differences across regions and states, reflecting variations in network conditions and exposure to weather-related risks [136].

Malaysia’s mitigation and resilience efforts are supported by a wider ecosystem of policies, including the NDC Roadmap, the Long-Term Low Emissions Development Strategy (LT-LEDS), the Renewable Energy Roadmap (MyRER), the National Energy Efficiency Action Plan and the Low Carbon Mobility Blueprint, among others [128]. Together, these instruments aim to balance the energy trilemma: security, affordability, and environmental sustainability, while creating new economic opportunities. NETR estimates that the transition could mobilize USD 295-320 billion (MYR 1.2–1.3 trillion) in investments and generate around 310,000 jobs by 2050, with particular benefits for medium- and low-income households through new income streams in green sectors [131]. When viewed together, the Malaysia Adaptation Index, the ESI reform analysis, the ASEAN grid studies and NETR outline a converging trajectory: climate risks are increasingly recognized and mapped; regulatory reforms are building a more flexible and competitive power sector; regional interconnections are being planned with resilience in mind; and regional transition strategies place diversification, infrastructure reinforcement and long-term resilience at the center of Malaysia's energy future [128–131].

3.11 Mexico

Mexico's National Electric System (SEN) is one of the largest in Latin America, with around 87 GW of installed generation capacity in 2023, of which roughly half is owned and operated by the state-owned Federal Electricity Commission (CFE) and the remainder corresponds to independent power producers and private plants connected to the grid [137,138]. The generation mix remains dominated by fossil fuels, particularly combined-cycle gas plants, although hydropower and a growing fleet of wind and solar projects already provide a significant share of capacity and government planning documents foresee substantial additions of clean capacity over the next decade [137,138]. Within this structure, energy resilience is framed primarily in terms of the reliability, continuity and security of the SEN, under a broader objective of guaranteeing a competitive, sufficient, high-quality and environmentally sustainable electricity supply. The Ministry of Energy (SENER) explicitly defines its mission as steering local energy policy so that the sector guarantees secure and high-quality supply while supporting sustainable development and energy security, and coordinates with CFE and the National Center for Energy Control (CENACE) on system planning and operation [139,140].

In operational terms, reliability indicators for Mexico's electricity distribution system have improved in recent years. According to SENER's Energy Information System, the average user experienced 1.18 interruptions per year (SAIFI) and 62.4 minutes without service (SAIDI) in 2018, while by 2022 these values had fallen to about 0.93 interruptions and 42.1 minutes per user (reductions of roughly 27% and 33%, respectively) and further improvements were reported in the first half of 2023 [141]. However, a large economy-wide disturbance on 28 December, 2020 illustrated the scale of systemic risks: an imbalance between load and generation in the National Interconnected System caused the loss of around 7,500 MW and left about 10.3 million users temporarily without power before automatic protection schemes and coordinated actions by CENACE and CFE limited the event and allowed service to be restored [142]. From a climate perspective, the General Law on Climate Change (LGCC) provides the overarching framework for mitigation and adaptation, mandating a National Adaptation Policy and requiring federal entities to carry out vulnerability diagnostics in the energy sector and integrate adaptation criteria into sectoral programs [143]. Under this framework, the Special Climate Change Program 2021–2024 (PECC) includes a specific line of action to prepare the Vulnerability Diagnosis of the Energy Sector to Climate Change (DVSECC), whose objective is to identify risks from hydrometeorological extremes to strategic electricity and hydrocarbons infrastructure and to define adaptation measures for operators such as CFE, CENACE and PEMEX [144,145].

At the sectoral level, the Sectoral Energy Program 2020–2024 sets regional energy-policy principles with explicit emphasis on energy security and diversification, energy savings and environmental protection, and calls for improving the reliability and quality of electricity supply for end-users [146,147]. The National Electric System Development Program (PRODESEN), now being replaced by the new Electricity Sector Development Plan (PLADESE), is the main public-policy planning instrument for the SEN; issued annually by SENER with a 15-year horizon, it details generation and network expansion consistent with regional policy objectives and explicitly aims to safeguard the reliability, continuity and security of the grid [140,148]. On the regulatory side, the former Electricity Industry Law (LIE) mandated SENER and the Energy Regulatory Commission (CRE) to promote the efficiency, quality, reliability, continuity, safety and sustainability of the SEN and provided the legal basis for technical standards and reliability criteria, including the issuance of Official Mexican Standards (NOMs) for installations and equipment [149,150]. In 2020, the government adopted the "Reliability, Security, Continuity and Quality Policy for the SEN," an administrative instrument that operationalize these principles in system planning and operation, with a particular focus on system security under increasing penetration of variable renewables [151]. In 2025, the new Electricity Sector Law (LSE) replaced the LIE but preserved as a key public-policy objective the provision of reliable, affordable, safe and clean electricity, reaffirming the obligation of sector participants to comply with the regulatory and standardization framework issued by SENER [152].

The microgrid market in Mexico is experiencing significant growth, driven by the need for reliable power supply and energy security [153]. Projections indicate that the market size will reach approximately USD 1.12 billion by 2033, with a compound annual growth rate (CAGR) of 8.72% from 2025 to 2033 [154]. In 2025, the Energy Regulatory Commission (CRE) established a regulatory framework for energy storage systems, facilitating their integration into the National Electric System and promoting grid stability [155]. In 2023, the Comisión Federal de Electricidad (CFE) initiated the deployment of approximately 30.2 million smart meters as part of the region's grid modernization efforts. The World Bank emphasized the vulnerability of Mexico's electricity infrastructure to natural hazards and recommended investments in resilient infrastructure to mitigate these risks [156].

Although Mexico a dedicated local energy resilience fund for Mexico was not identified, existing international mechanisms such as the Green Climate Fund (GCF) provide financing for climate adaptation and resilience and are currently active in the economy [157]. This climate fund aims to support developing regions in reducing greenhouse gas emissions and enhancing resilience to the impacts of climate change. The GCF is currently supporting projects in Mexico with a total financing amount of USD 169.4 million [158]. According to the fund's investment framework and guidelines, resilience in the energy sector can be addressed through this mechanism. From an adaptation and resilience standpoint, the DVSECC identifies priority risks for generation plants, transmission and distribution lines and hydrocarbons facilities under scenarios of more frequent and intense floods, hurricanes, heatwaves and other climate-driven hazards, and compiles concrete adaptation measures already being implemented by CFE, CENACE and PEMEX, such as reinforcement of transmission and distribution assets, updated design standards for substations in flood-prone areas and operational protocols for extreme events [144,159]. Taken together, Mexico's approach to energy resilience is articulated through climate law and adaptation options that seek to reduce vulnerability and increase the resilience of strategic infrastructure, and through energy-sector planning and regulation that place reliability, continuity and security of supply at the center of policy goals [139- 144,146-152]. The improvement in SAIDI and SAIFI indicators and the controlled management of the 2020 economy-wide disturbance can be interpreted as early evidence of this framework in action, illustrating both current strengths and remaining challenges for the resilience of the SEN in the face of climate and operational shocks.

3.12 New Zealand

New Zealand has a relatively small but highly renewable electricity system, with a high share of hydropower and geothermal generation, complemented by wind power and a smaller contribution from gas- and coal-fired thermal plants [160,161]. The sector is governed by the Electricity Industry Act 2010, which establishes the regulatory framework for the electricity industry, creates the Electricity Authority as the regulator of wholesale and retail markets, and defines its core objective as promoting an efficient, reliable and secure supply of electricity for the long-term benefit of consumers [162,163]. Transmission assets are owned and operated by Transpower, which manages the local grid and coordinates generation dispatch, making it a central actor in both operational security and long-term resilience planning [163,164].

The main risks and impacts on New Zealand's energy resilience are linked to its heavy reliance on hydropower (making the system vulnerable to so-called "dry years") and to the exposure of transmission and distribution infrastructure to flooding, landslides, storms and other climate-related hazards [165,166]. The National Disaster Resilience Strategy (NDRS), led by the National Emergency Management Agency (NEMA), sets out a vision of a "resilient Aotearoa" and explicitly recognizes electricity networks and other lifelines as essential infrastructure that must be able to withstand and recover from disasters [167]. In quantitative and planning terms, the first Emissions Reduction Plan sets a target of achieving 100% renewable electricity under normal hydrological conditions by 2030, while acknowledging that dry-year risks require dedicated solutions such as the New Zealand Battery Project to maintain security of supply without relying on coal or gas during adverse hydrological periods [161,166]. The government notes that New Zealand already generates around 80–85% of its electricity from renewable sources, which reinforces the low-carbon nature of the system but also demands careful management of hydrological variability and climate risk [160,166].

Energy-resilience policies are organized around three interlinked pillars. First, the legal and regulatory framework: in addition to the Electricity Industry Act, the National Policy Statement for Renewable Electricity Generation recognizes renewable generation as being of "local significance" within the land-use planning system, helping to facilitate the development of renewable projects and associated transmission infrastructure needed to strengthen long-term security and resilience of supply [160,163]. Second, climate policy: the National Adaptation Plan 2022–2028 sets actions to incorporate climate risk into the planning, design and operation of critical infrastructure, including energy, driving regulatory and institutional changes so that new and existing assets account for flooding, sea-level rise and other hazards [165]. Third, the forthcoming New Zealand Energy Strategy, whose design is being led by MBIE; background documents on Advancing New Zealand's Energy Transition indicate that this strategy will need to balance decarbonization, security of supply and resilience, explicitly addressing the dry-year problem, the future of gas and the integration of distributed generation [166].

These policy pillars are supported by a set of public investment and regulatory funding mechanisms aimed at strengthening energy system resilience. In New Zealand, funding related to energy resilience mainly comes from local infrastructure planning, climate adaptation programs, and regulated investment in the electricity sector, rather than from a single dedicated resilience fund. Through the National Infrastructure Plan and successive government budgets, substantial public resources have been committed to strengthening critical infrastructure, including electricity networks, with a strong focus on resilience to natural hazards such as earthquakes, storms, and flooding. Recent budget and infrastructure planning documents show that at least USD 20 billion (around NZD 32 billion) has been allocated over the medium term to infrastructure and resilience-related investments, with electricity transmission and distribution identified as priority areas for maintaining a reliable and secure power supply [168–170]. These efforts are supported by New Zealand's National Adaptation Plan, which highlights the need to protect critical energy infrastructure and improve recovery following extreme weather events [171]. In parallel, regulated capital expenditure by the local grid operator focuses on reinforcing and upgrading transmission assets to maintain security of supply and support faster system recovery after disruptions [172]. Together, these funding and policy frameworks help New Zealand withstand shocks, recover more efficiently, and strengthen its energy system over the long term [168–172]. Electricity distribution reliability in New Zealand is monitored through a comprehensive information disclosure framework overseen by the Commerce Commission, using internationally recognized indicators such as SAIDI and SAIFI to measure the duration and frequency of power outages experienced by customers. According to the industry-wide electricity distribution performance summary for the year ending 31 March 2024, the local average SAIDI was about 290 minutes per customer per year, while SAIFI averaged 2.39 interruptions per customer per year, reflecting the combined performance of all electricity distribution businesses across the economy [173]. The Commerce Commission's explanatory notes confirm that these indicators include both planned and unplanned outages and provide a consistent basis for comparing reliability across networks and over time [174]. Overall, these results show the system's exposure to weather-related and external disruptions, while also underlining the importance of continued network upgrades, asset renewal, and resilience-focused investment to reduce outage impacts and improve recovery from extreme events.

Among specific initiatives and emerging success cases, a central role is played by the joint program of the Electricity Authority and Transpower on Future Security and Resilience (FSR). Its phase 1 report identifies opportunities and challenges for future security and resilience in a context of high renewable penetration and electrification and proposes a multi-phase roadmap to monitor and manage evolving risks [175]. At company level, Transpower has prepared a Climate Adaptation Plan that states that preparing for and responding to climate change is “integral” to its business, detailing measures to improve the resilience of the transmission network through identification of vulnerable assets, review of design standards, prioritization of reinforcements and relocations, and the incorporation of climate risk into investment planning and day-to-day system operation [164,175]. Taken together, New Zealand’s energy resilience rests on a clear legal and regulatory framework, decarbonization policies that combine high renewable targets with specific instruments to manage hydrological risk, and a climate-resilience and adaptation architecture that integrates energy infrastructure into local disaster and climate-change strategies [161,167,175].

3.13 Papua New Guinea

Papua New Guinea’s energy system is characterized by a strong dependence on fossil fuels combined with very low levels of domestic utilization of its own resources. Liquefied Natural Gas is a fundamental pillar of the local economy, yet domestic use remains limited because the midstream industry is still underdeveloped: although it produces gas and oil, more than 90% of these resources are exported, and around 85% of petroleum-derived fuels circulating in it are imported, while only a small fraction of natural gas is used locally [176]. At the same time, the electricity access gap is severe: only about 20% of the population is connected to the power system, and in rural areas less than 15% has access [177]. This context shapes both the structure of the energy matrix and the priorities of energy policy, which must simultaneously expand access, improve reliability and address climate-related vulnerability, often in close coordination with international partners such as the World Bank, Australia and the Global Green Growth Institute [177,178]. PNG Power Limited (PPL), the state-owned utility, operates three major grids and several isolated diesel-powered mini-grids, which are expensive to maintain and suffer from low efficiency. Network losses are high, governance has historically been weak, and tariff settings have not reflected actual costs, limiting the sector’s financial sustainability [179, 180]. Diesel supply issues and inadequate technical capacity exacerbate load shedding and unplanned outages. High operation costs, low sales growth, and unbilled consumption have impacted financial performance in past years [181].

The main threats to energy resilience in Papua New Guinea stem from climate risks and geographic fragmentation. If current climate trends continue, disasters such as floods, droughts and landslides (like the event in Enga in 2024) are expected to intensify in frequency and severity, directly affecting energy infrastructure, rural mini-grids and transport corridors [176]. Without effective adaptation and risk-management measures, the economic cost associated with sea-level rise alone could reach 0.3% of

GDP by 2050 [176]. The geographic dispersion of rural communities and difficult terrain make the construction of a fully integrated regional grid challenging, which not only constrains the extension of conventional networks but also increases the cost and complexity of operating and maintaining infrastructure under extreme weather conditions [182]. In this setting, the resilience of the energy system depends as much on the robustness of central assets as on the ability to deploy decentralized, context-appropriate solutions in exposed and hard-to-reach areas [176,182].

Regional energy resilience financing was not identified. Nonetheless, Papua New Guinea has programs and policies that address energy resilience within the economy. Policy and planning responses increasingly reflect this dual challenge of access and resilience. The World Bank–supported NEAT project, approved at the end of 2023, aims to provide around USD 92,000 (PGK 400,000) with access to reliable electricity through a combination of grid extension, microgrids and solar home systems, while promoting greater use of renewable energy sources [177]. These interventions are projected to raise regional electrification to close to 70% by 2030 and are explicitly designed to favor technologies that can withstand dispersed demand, difficult terrain and climate-related disruptions [177,182]. Decentralized solutions (particularly solar) are identified as a feasible alternative to meet access targets in remote communities; however, their effective deployment depends on enabling regulation, the economic viability of projects and the willingness and capacity of communities to adopt and manage new systems [182].

Emerging climate-finance initiatives also play a central role in building resilience. The Climate FIRST project (Finance Initiative for Resilience and a Sustainable Transition), launched in 2024 with an Australian contribution of USD 13 million (AUD 20 million), seeks to mobilize and secure regional and international climate funds for resilient and transformative adaptation and mitigation projects in Papua New Guinea [178]. With an initial duration of at least four years and joint governance between institutions from both economies, implemented by the Global Green Growth Institute, Climate FIRST is designed as a platform to channel investment into projects that strengthen the robustness of critical infrastructure, diversify the energy mix and support low-carbon, climate-resilient development [178]. Together, initiatives such as NEAT and Climate FIRST illustrate how Papua New Guinea is beginning to link electrification, decentralized renewables, climate adaptation and dedicated finance mechanisms into an emerging framework for energy resilience in an archipelagic, climate-vulnerable context [176-178, 182].

3.14 Peru

Peru's electricity sector is organized around the National Interconnected Electric System (SEIN), which supplies most regulated and free customers and is coordinated by the Comité de Operación Económica del Sistema Interconectado Nacional (COES), a private, non-profit ISO whose decisions are binding for all market agents (generators, transmitters, distributors and large users) under public oversight [183]. According to the Electricity Statistical Yearbook of the Ministry of Energy and

Mines (MINEM), electricity production in 2020 reached around 53 TWh, with 58% generated from hydropower, 37% from thermal plants and about 5% from non-conventional renewables (solar and wind), serving nearly 7.8 million customers [184]. This mix shows both Peru's structural dependence on hydrological conditions and the still modest but growing contribution of variable renewables, which are increasingly seen as central to long-term energy resilience strategies [184]. The policy framework for the sector is defined by the National Energy Policy of Peru 2010–2040, approved by Supreme Decree No. 064-2010-EM, which envisions an energy system that meets demand reliably, continuously, efficiently and sustainably, with a diversified mix and greater participation of renewables and energy efficiency, explicitly setting objectives of security of supply, quality of service and environmental sustainability [185]. Based on this roadmap, MINEM's National Energy Plan 2014–2025 develops demand and supply scenarios, identifies investments in generation and networks and emphasizes the need to avoid bottlenecks in transmission and distribution in order to guarantee medium-term security of supply [186].

Peru has had Framework Law No. 30754 on Climate Change since 2018, which recognizes climate change as a threat to sustainable development and establishes mitigation and, above all, adaptation obligations for productive sectors, including energy [187]. The law defines principles, objectives and institutional arrangements, assigning the Ministry of the Environment (MINAM) the role of lead agency for climate policy and requiring coordination with MINEM to reduce the vulnerability of energy infrastructure and services to climate-related hazards [187]. In 2022, Supreme Decree No. 003-2022-MINAM declared the climate emergency to be of local interest, reinforcing the urgency of implementing NDCs and protecting critical infrastructure from the impacts of climate change [188]. On the regulatory side, the Technical Standard for the Quality of Electricity Services (NTCSE), approved by Supreme Decree No. 020-97-EM, sets minimum quality levels for generation, transmission and distribution companies, including limits on interruption frequency and duration, voltage-quality requirements and obligations for service restoration [189]. According to Osinergmin, the NTCSE regulates the quality aspects of electricity service that companies must comply with under the Electricity Concessions Law, establishing minimum quality levels and obligations for both companies and customers [190]. This combination of technical standards and regulatory oversight directly supports the operational resilience of the SEIN by reducing the risk of blackouts, congestion and prolonged failures [189,190].

Reliability in distribution networks is monitored through SAIDI and SAIFI indicators, supervised by Osinergmin within the framework of the NTCSE and specific supervisory procedures [189,191]. For typical urban systems such as Lima Metropolitana, the regulator sets tolerances of up to three interruptions per semester with a cumulative duration of 6.5 hours, while in rural "sector típico 4" systems the tolerance can reach 16 interruptions and 40 hours over the same period, reflecting the greater exposure and complexity of remote networks [189,191]. Special monitoring reports show how these indicators are stressed by extreme events: in the week from 29 March to 4 April 2023, Osinergmin recorded 90 major interruptions locally, 30% of which were attributed to natural phenomena [192]. During the same period, intense rains associated with Cyclone Yaku triggered landslides and debris flows that damaged multiple towers along the 500 kV Campas–Carapongo transmission line, forcing the temporary suspension of works and illustrating how climate-related hazards can directly affect critical expansion projects in the SEIN and increase the urgency of resilience-oriented planning and standards [192].

These operational stresses and climate-related disruptions underscore the need for sustained investment in energy system resilience. In Peru, funding related to energy resilience mainly comes from local development plans, climate adaptation policies, and sector-specific investment programs, rather than from a single dedicated resilience fund. Through the National Infrastructure Plan for Competitiveness (PNIC) and its updated successor (2022–2025), the government prioritizes investment in electricity transmission, distribution, and energy security, with a strong focus on maintaining a reliable and continuous power supply. Official planning documents show that public and public-private investment commitments under these infrastructure plans total about USD 25–30 billion, with a significant share directed to energy and electricity infrastructure, including the expansion and reinforcement of transmission networks in geographically complex and climate-exposed regions [193, 194]. These investments are supported by Peru's National Climate Change Strategy to 2050 and related sectoral plans, which stress the need to protect critical infrastructure, including energy systems, from climate-related risks such as floods, landslides, and earthquakes [195]. Together, these policy and investment frameworks help the power system withstand disruptions, recover more quickly, and strengthen infrastructure over the long term [193- 196].

On the climate side, the National Adaptation Plan to Climate Change of Peru: an input for updating the National Strategy on Climate Change, approved by Ministerial Resolution No. 096-2021-MINAM, identifies infrastructure and basic services (including energy) as one of the priority areas for reducing risks and vulnerabilities associated with glacier retreat, changes in hydrological regimes and extreme events [197]. The PNACC promotes risk-management measures, land-use planning and the strengthening of critical infrastructure and is articulated with the NDCs and ongoing revisions of energy policy to accelerate the incorporation of renewable energy and energy efficiency as part of a transition that is both low-carbon and resilient to climate impacts [187,197]. Taken together, the Peruvian framework shows that energy resilience is built on four interacting pillars: a climate framework that formally recognizes the climate emergency and assigns specific responsibilities to MINAM and MINEM for adaptation in the energy sector [187,188]; a regional energy policy oriented toward supply security, continuity and quality of service [185,186]; technical quality regulation supervised by Osinergmin that requires companies to comply with strict continuity and quality standards [189,190]; and long-term climate planning through the PNACC, which integrates energy infrastructure as a key component of adaptation [197]. Although the term "energy resilience" does not always appear explicitly in the regulations, the combined focus on security, reliability, service continuity and climate-change adaptation effectively functions as Peru's core strategy for strengthening its power system in the face of extreme events and structural changes in demand [183-192,197].

3.15 The Republic of the Philippines

The operation and structure of the Philippines’ energy system are shaped by its geographic fragmentation into three main grids (Luzon, Visayas and Mindanao) and 148 “off-grid” areas served by the Small Power Utilities Group (SPUG) of the National Power Corporation (NPC) [198]. Governance is defined by the Electric Power Industry Reform Act (EPIRA) of 2001, which unbundled the sector and privatized operation under a concession model: while transmission assets remain under state ownership through TransCo, their operation, maintenance and expansion are the responsibility of the private National Grid Corporation of the Philippines (NGCP) [198, 199]. Within this framework, and in a system where coal still accounts for almost 60% of generation (2022) and interconnection has historically been limited, the long-term strategic vision of “One Grid Philippines” seeks to integrate the three main grids and reduce dependence on individual island systems, through projects such as the Mindanao–Visayas Interconnection Project (MVIP), in order to enable a more resilient flow of power and balancing capacity between regions [198,200].

The Philippines is classified as the fourth most vulnerable economies in the world according to the Climate Risk Index and faces critical exposure that directly affects energy infrastructure, with an average of around 20 typhoons per year [201]. These events have generated cumulative damages of USD 111.4 million (PHP 6.55 billion) for Electric Cooperatives (ECs) between 2014 and 2020, exacerbated by extreme disasters such as Super Typhoon Odette [199]. Seismic risks associated with the Ring of Fire compound this exposure and are addressed under the National Energy Contingency Plan (NECP), which considers, among others, the scenario of a magnitude 7.2 earthquake affecting Manila and its energy systems [199, 201]. Operationally, high natural hazard exposure, combined with tight reserve margins, has translated into frequent red and yellow alerts, with an estimated economic cost around USD 4.2 (PHP 247.8) for every kWh of lost load, underlining the urgency of developing climate-risk-proof energy infrastructure and strengthening both adequacy and resilience [198, 199]. From a reliability standpoint, the Philippines’ power system still exhibits a significant gap compared with regional benchmarks, with a SAIDI of 3.57 hours and SAIFI of 2.23 interruptions in 2020 [201]. These averages, however, conceal extreme disparities in rural areas, where ECs have accumulated around USD 170 million (PHP 10 billion) in reconstruction requests due to force majeure events between 2008 and 2023, reflecting financial constraints and high exposure to disasters [199].

To address these challenges, the Department of Energy (DOE) has introduced tools such as the Energy Resiliency Scorecard (ERS) and the Energy Resiliency Assessment Framework (ERAFM), designed to quantify the technical and financial capacity of facilities to withstand disasters and to condition access to insurance and financing on minimum resilience standards [199]. To address energy resilience, the

Philippines enacted Republic Act No. 11039, institutionalizing the Electric Cooperatives Emergency and Resiliency Fund as a dedicated financial mechanism to support post-disaster rehabilitation and resilience investments for electric cooperatives [202]. Additionally, strategic resilience policies were articulated mainly through the Philippine Energy Plan (PEP) 2023–2050, which sets the mandate to build climate-proof energy infrastructure and achieve self-sufficiency by mid-century [200]. To operationalize this vision, the regulatory framework includes the Resiliency Compliance Plan (RCP), which obliges participants in the electricity industry to submit annual structural and financial strategies to ensure continuity of operation in the face of events that may affect the energy mix or system performance [199]. Extreme-risk management is further institutionalized through the NECP, which incorporates the "Build Back Better" principle to raise engineering and reconstruction standards after disasters and to ensure that post-event investments result in more robust systems rather than merely restoring pre-disaster conditions [199]. In terms of concrete success cases, the MVIP stands out as a landmark project under the "One Grid Philippines" vision: since 2024 it has strengthened infrastructure by enabling the unification of the three main grids with a transfer capacity of 450 MW, facilitating economy-wide reserve sharing and enhancing resilience against regional failures [198,200,203]. Complementarily, the Microgrid Systems Act (MGSA) has helped unlock investment in hybrid systems for unserved and underserved areas, while the implementation of the first Energy Transition Mechanism (ETM) for coal plant retirement has established a replicable financial model that supports both decarbonization and resilience objectives, contributing to a reported 30% improvement in energy intensity since 2005 [198,200].

3.16 Russian Federation

The Russian Federation's electricity sector is organized around the Unified Energy System (UES), one of the largest interconnected power systems in the world, where regional power systems are linked through high-voltage lines operating between 220 kV and 750 kV in synchronous mode, enabling large-scale power transfers between regions and supporting system stability under contingencies [204]. According to IRENA, total electricity generation in 2023 was about 1,147 TWh, of which around 81% came from non-renewable sources and 19% from renewables; hydro and marine power provided close to 18% of total generation, while solar and wind together contributed about 1%, meaning the system is dominated by gas- and coal-fired thermal generation complemented by large hydropower and a still modest but expanding portfolio of variable renewables [205]. The operation and market organization of this system are governed by Federal Law No. 35-FZ "On the Electric Power Industry", which defines the roles of market participants and assigns to the system operator and dispatch entities the responsibility for ensuring compliance with reliability and quality parameters, requiring that dispatch decisions prioritize secure, accident-free supply and power quality in accordance with technical requirements [206].

In Russia, energy resilience is understood primarily through the lens of energy security and the stability of the fuel and energy complex. The core document is the

Energy Security Doctrine of the Russian Federation, approved by Presidential Decree No. 216 of 13 May 2019, which forms part of regional strategic planning on security, identifies internal and external threats to energy security and defines measures to ensure reliable energy supply throughout the territory [207]. The Doctrine stresses the importance of maintaining the stability of the fuel and energy complex in the face of sanctions, price shocks, technological accidents and extreme weather conditions, and is coordinated with other regional security and economic-development strategies [207]. At the level of sectoral planning, the Energy Strategy of the Russian Federation to 2035, endorsed by Government Resolution No. 1523-r of 9 June 2020, sets long-term objectives such as guaranteeing security of supply, improving infrastructure reliability, diversifying energy exports and increasing energy efficiency, while preserving competitiveness in international hydrocarbon markets [208]. The Energy Strategy is designed to be consistent with the Energy Security Doctrine and guides investment decisions in generation, transport and transformation infrastructure in order to reduce vulnerabilities to external crises and internal emergencies [207,208].

In practice, the reliability of electricity supply to end-users is very high. World Bank Doing Business assessments for Moscow and Saint Petersburg report a SAIDI of around 0.2 hours per customer per year and a SAIFI of about 0.1 outages per customer per year, and the economy earns the maximum score on the "reliability of supply and transparency of tariffs" index [209]. At the transmission level, the System Operator of the Unified Energy System indicates that in 2023 electricity demand reached a new historical winter peak of 168,741 MW while system frequency remained within the limits of the local standard GOST R 55890-2013, illustrating robust balancing and emergency-control capabilities under stress [210]. These indicators suggest that legal requirements on reserve margins, automated monitoring and restoration tools, and performance-based regulatory incentives have so far kept interruptions infrequent and short in Russia's interconnected power system [206,209,210].

On the climate side, adaptation and low-emission development policies are increasingly integrated into the energy-security agenda. The National Action Plan for the first stage of adaptation to climate change up to 2022, approved by Government Order No. 3183-r of 25 December 2019, sets out economic and institutional measures to reduce the vulnerability of the population, the economy and ecosystems to climate impacts and explicitly recognizes the fuel and energy complex as a priority sector for adaptation, given the risks associated with permafrost thaw, flooding, heat waves and other phenomena that can affect pipelines, power plants and related infrastructure [211]. In 2021, the Strategy for the Socio-Economic Development of the Russian Federation with Low Greenhouse Gas Emissions until 2050, approved by Government Order No. 3052-r, defined low-emission growth pathways, improvements in energy efficiency and the deployment of renewable energy and hydrogen technologies, linking climate transition with energy security objectives [212]. This framework was complemented by the new Climate Doctrine of the Russian Federation, approved by Presidential Decree No. 812 of 26 October 2023, which replaces the 2009 doctrine, provides the basis for Russian climate policy and mentions the possibility of achieving carbon neutrality around 2060 as an extension of the low-emission strategy to 2050 [212,213]. Russia's

Nationally Determined Contributions under the UNFCCC, in turn, refer to the creation of a local adaptation system and highlight the need to adapt the infrastructure of the fuel and energy complex to climate risks, underscoring the dual role of the energy sector in mitigation and adaptation [214].

The Russian Energy Strategy to 2035 frames resilience financing as a core element of local energy security, led by the federal government and coordinated by the Ministry of Energy, with implementation embedded in state programs and strategic planning instruments approved by the Government of the Russian Federation (pp. 1–3). Financing relies primarily on public and regulated investment mechanisms, complemented by state-supported private capital, with total investment in the fuel and energy complex estimated at around RUB 40 trillion for 2018–2024, aimed at infrastructure modernization, system reliability, and long-term stability under economic and climatic uncertainty (p. 10). Resilience is thus pursued through centralized strategic control, long-term investment horizons, and alignment with local security and development objectives rather than through a standalone resilience fund [215]. In the Russian Federation, local SAIDI and SAIFI values are not publicly reported in a consistent way. Instead, international benchmarking shows high electricity supply reliability. According to the World Bank's Doing Business 2020 report, Russia scores the maximum 8 out of 8 on the Reliability of supply and transparency of tariff index, indicating strong outage monitoring, rapid service restoration, and effective regulatory oversight [216]. While this index does not provide specific SAIDI or SAIFI figures, it suggests that power outages are generally limited and that the electricity system performs well by international standards.

Taken together, the Russian experience shows that energy resilience is addressed mainly through an integrated framework of energy security, system reliability and climate adaptation. The Energy Security Doctrine provides the strategic basis for identifying threats and protective measures [134]; the Energy Strategy 2035 translates these into sectoral lines of action with an emphasis on infrastructure reliability and security of supply [208]; the Federal Law on the electric power industry and the organization of the Unified Power System incorporate operational requirements aimed at preventing large-scale failures [206]; and the adaptation plan, low-emission development strategy and new Climate Doctrine link these security objectives with responses to climate risks and long-term decarbonization [212-214]. Although the term "energy resilience" is not always used explicitly, the combination of these instruments, supported by very low SAIDI and SAIFI values and stable system performance at record peaks, functions in practice as the core of Russia's energy-system resilience strategy [204-206,209,210].

3.17 Singapore

Singapore conceptualizes power system resilience from an ecological perspective, as the magnitude of disturbance that can be absorbed before the system shifts into a different structural state, that is, its capacity to persist and adapt in the face of shocks [217]. This framing underpins efforts to build a flexible and adaptive electricity system. In practice, Singapore's power system is already among the most reliable in the world, with only around 0.25 hours of electricity interruptions recorded in 2016–2017 [218]. System governance is led by the Energy Market Authority (EMA), which regulates the electricity and gas sectors and is responsible for maintaining security of supply while the economy transitions toward cleaner energy sources, including solar power and low-carbon electricity imports [219]. EMA's approach to resilience includes contingency planning based on real-time consumption data from smart meters and simulations for short-term demand forecasting, particularly for essential services [219, 220]. A key emerging avenue is the use of prescriptive analytics and generative artificial intelligence (GenAI) to detect patterns, trends and vulnerabilities in system operation; to enable this, EMA is investing in big-data platforms, advanced modelling and GenAI training for its staff in collaboration with other government agencies and industry stakeholders [220]. EMA also emphasizes the role of temporary regulatory exemptions and "sandbox" environments to test new products and services safely, facilitating innovation that can strengthen system resilience without compromising security [221].

Parallel to digital modernization, Singapore reinforces energy resilience through a strong security-of-supply strategy. More than 93% of its electricity generation currently comes from natural gas delivered via pipelines from neighboring areas or regions, a concentration that creates exposure to supply disruptions [222]. To mitigate this risk and diversify sources, Singapore has positioned itself as an LNG hub: it operates a large LNG import terminal that has been in service for over a decade and is planning a second facility as a Floating Storage and Regasification Unit (FSRU) [222]. Looking ahead, Singapore aims to use low-carbon energy to align with its net-zero emissions target for 2050 and is assessing the potential use of nuclear power from around 2040 as part of a broader diversification strategy to strengthen energy security, sustainability and resilience [222]. To support these transitions, Singapore is considering allocating more than USD 7 billion to its Future Energy Fund and plans to deploy 200 MW of storage capacity by 2035 to help balance demand variations and maintain system reliability as variable renewables and imports grow [222].

On the generation side, the installed-base renewable energy market is expected to grow to about 2.5 GW by 2030, reflecting increasing demand for clean electricity and rising investment [223]. New generation projects are required to be at least 30% hydrogen-ready, signaling that technological modernization is oriented toward renewable-based hybrid solutions and future low-carbon fuels [223]. Solar energy is the main pillar of domestic renewable expansion: it is a scalable local resource in a land-constrained city-state and supports rooftop, floating and near-shore configurations [223].

The government has allocated around USD 6.2 million in R&D grants to develop solar-forecasting models, improving the ability to integrate solar generation while managing intermittency [223]. Solar already accounts for an estimated 84.7% of Singapore's renewable market in 2025 and is projected to grow at a compound annual rate of about 9% through 2030, with new floating solar parks planned at the Kranji and Pandan reservoirs by 2030 [223]. Together, the ecological framing of resilience, EMA's data- and AI-driven planning, diversification via LNG and prospective nuclear and hydrogen-ready capacity, and the scaling-up of solar and storage form a coherent strategy through which Singapore seeks to maintain one of the world's most reliable power systems while increasing its resilience to climate, market and technological disruptions [217–223].

In Singapore, no dedicated financing mechanism for energy resilience was clearly identified during the review. However, as mentioned above, resilience is addressed through a broader strategic and regulatory framework, such as EMA-led contingency planning, data-driven system operation, and supply diversification.

3.18 Chinese Taipei

Chinese Taipei's electricity system remains dominated by thermal generation, which represents close to 70% of installed capacity, primarily from coal and natural gas with a smaller share from oil, while nuclear contributes about 12% and renewables around 18%, mainly from solar and wind that have expanded significantly over the past decade [224]. Despite this growth, the transition has not yet substantially decarbonized the mix: the phase-out of nuclear power has offset part of the renewable expansion, so that carbon-free capacity declined from 16.81% in 2016 to 15.48% in 2024, even though renewable generation rose from 4.8% to 11.1% and cumulative installed capacity increased by 16 GW since 2016; Chinese Taipei remains about 6.4 GW short of its 2025 renewable capacity target [225]. Sector governance is highly centralized under the vertically integrated Taiwan Power Company, which oversees generation, transmission and distribution across the whole territory, operating under the Electricity Act and accompanying technical regulations [224,226]. This model has delivered generally reliable service but concentrates responsibility for planning and resilience measures in a single operator that must prepare for both energy transition and climate-related risks [224,226].

The main threats to energy resilience are associated with geography and climate. Chinese Taipei's location exposes its electricity infrastructure to recurrent typhoons, earthquakes, extreme rainfall, landslides and flooding, which can damage transmission lines, substations and power plants in ways comparable to the challenges observed in Japan and the Republic of Korea [224]. Regulations related to resilience arise indirectly through broader legal and planning obligations: under the Electricity Act, the Disaster Prevention and Protection Act and grid codes, power operators are required to meet standards for system reliability, emergency response, typhoon and earthquake preparedness and secure integration of high shares of renewables, creating a de facto regulatory environment for resilience even in the absence of a single dedicated "resilience law" [226]. In parallel, Taiwan Power Company has implemented a suite of technical and digital upgrades that together strengthen system robustness, including smart grid technologies, automated outage management, real-time monitoring systems, expanded energy storage and progressive modernization of network assets [224]. These measures function as practical resilience strategies by improving the capacity to anticipate, withstand, and recover from climate and operational disturbances.

Energy transition policies seek to move away from a model centered on nuclear and fossil fuels towards one based on renewables and greater societal participation. Local governments have been particularly active in expanding solar PV deployment, often more proactively than the central administration, through rooftop programmes and local initiatives, contributing to a more decentralized and participatory configuration of the energy system that is consistent with the concept of energy democracy [227]. This distributed approach is relevant for resilience because community-level projects, local ownership and diversified generation nodes can improve response and recovery during extreme events or large outages [227]. At the regional level, two key policy instruments guide the direction of change. The Renewable Energy Development Act, updated in 2019, provides the legal basis for renewable deployment and sets the 27 GW by 2025 target, making it the central framework for scaling renewables [225]. The Climate Change Response Act of 2022 embeds Just Transition principles into climate and energy policy, requiring consultation with affected communities and emphasizing human rights and decent work, recognizing that the transition must be both socially inclusive and equitable [225].

These policy commitments and governance arrangements are supported by substantial long-term investment in grid reinforcement and system resilience. In Chinese Taipei, funding related to energy resilience mainly comes from multi-year infrastructure programs and sector-specific investment plans, rather than from a single dedicated resilience fund. To strengthen electricity system reliability and emergency response, Taiwan Power Company (Taipower) has launched a 10-year "Grid Resilience Strengthening Construction Plan", committing about USD 18–19 billion (NTD 564.5 billion) to major upgrades of the local power grid. These upgrades include distributed grid projects, network reinforcement, and added protection measures designed to reduce the risk of large-scale outages and speed up recovery after extreme events [228, 229]. Together, these investments help the power system withstand disruptions, improve operational readiness, and limit the social and economic impacts of power interruptions. In parallel, local climate adaptation policies highlight the need to protect critical infrastructure, including energy systems, and to strengthen resilience to climate-related hazards, supporting long-term system improvements [230]. Government statements also describe these grid investments as part of broader efforts to improve supply stability and overall system robustness [231]. Electricity distribution reliability in Chinese Taipei is measured using internationally recognized indicators. Taipower reports that in 2023 the SAIDI value was 15.225 minutes per customer, while SAIFI was 0.186 interruptions per customer [232]. These low levels of outage duration and frequency show that the power system performs well by international standards and reflect continued investment in grid reinforcement, operational preparedness, and system hardening to reduce the impact of disruptions and support fast service restoration.

A major structural innovation with direct implications for resilience and long-term system transformation is the 2019 amendment to the Renewable Energy Act introducing the Renewable and Storage Portfolio Standard (RSPS) [233]. This mechanism obliges large electricity users with contracted capacity of at least 5000 kW to source 10% of their consumption from renewable energy or storage systems, turning industrial and commercial consumers into active participants in the transition [233]. Compliance options include installing their own renewable or storage capacity, offering land or rooftops to project developers, signing long-term power purchase agreements, purchasing renewable energy certificate packages or paying an alternative compliance fee [233]. By creating a stable demand pool for renewable and storage projects and linking corporate behavior to explicit quantitative obligations, the RSPS operates as a policy tool that not only accelerates decarbonization but also supports resilience by diversifying the generation base, incentivizing storage deployment and expanding the number of actors investing in robust, low-carbon infrastructure [225,233]. Together, Chinese Taipei's centralized governance under Taiwan Power Company, its hazard-oriented regulatory framework, local renewable initiatives and the RSPS form an emerging resilience architecture that, while not always labelled explicitly as "energy resilience," integrates reliability, disaster preparedness, decarbonization and social participation into the evolution of its power system [224–227,233].

3.19 Thailand

Thailand, in line with the ASEAN definition of energy resilience as "the capability of an energy system to withstand and recover from high-impact events and reduce the duration, cost and impact of outages on critical services," is progressively reshaping its power system to cope with climate and security-of-supply risks [234]. The economy is among the most climate-vulnerable in the region, having experienced large-scale floods, droughts and severe storms with high mortality, which directly affect electricity infrastructure and highlight the need to strengthen resilience while decarbonizing the energy mix [235]. In response, Thailand has committed to achieving carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065, and to reducing its dependence on natural gas to improve energy security [235]. The NDC Roadmap (2021–2030) lays out mitigation measures in the energy sector (renewable electricity and energy efficiency), industrial processes and waste, aligning climate policy with the goal of steering Thailand toward sustainable development by 2050 and improving energy efficiency and security [235]. Within this framework, Thailand plans to increase the renewable energy share in power generation to 30% by 2037 and has decided not to grant new permits for coal-fired power plants, signaling a structural shift away from high-carbon technologies [235].

Thailand is shifting toward more competitive market mechanisms, using feed-in tariff auctions and green energy certificates to encourage private-sector participation [236, 237]. Planning frameworks like the PDP, the Alternative Energy Development Plan (AEDP), and OECD's Clean Energy Finance Roadmap all point to improving alignment across institutions [238, 239]. The next step will be scaling up these tools and ensuring that climate resilience becomes a core part of project planning and investment decisions.

From an operational perspective, recent reliability indicators show tangible improvements. In 2024, in the area served by the Metropolitan Electricity Authority

(MEA), the SAIFI stood at 0.508 interruptions per customer per year and the SAIDI at 15.13 minutes per customer per year, with both indices on a downward trend since 2018, indicating a gradual strengthening of the metropolitan grid's resilience [240]. At the same time, Thailand is deploying concrete engineering solutions that directly contribute to energy resilience by enhancing flexibility, storage and resource diversity. In 2021, the Electricity Generating Authority of Thailand (EGAT) commissioned what is described as the world's largest hydro-floating solar hybrid project, which generates electricity from solar power during the day and relies on hydropower when solar output is unavailable, improving security of supply at low cost with a capacity of more than 30 MW; EGAT plans to install similar floating solar-hydro hybrids at each of the economy´s dams by 2075 [241]. Complementing this, EGAT is investing about USD 2.5 billion (approximately THB 90 billion) in pumped-storage hydropower (PSH) systems at three major hydropower dams (Chulabhorn in Chaiyaphum, Vajiralongkorn in Kanchanaburi and Kathun in Nakhon Si Thammarat) to address the variability of solar and wind power and provide large-scale storage; commercial operation of these PSH projects is expected to begin in 2034, 2036 and 2037, respectively [242]. Together, Thailand's climate commitments, renewable expansion targets, improving reliability metrics and large-scale hybrid and storage projects illustrate an emerging resilience strategy that combines policy planning, market signals and infrastructure innovation to manage climate risks and strengthen the robustness of the electricity system [234–241].

Thailand is among the economies supported by the Green Climate Fund (GCF), which provides financing for climate adaptation and resilience. In Thailand's case, the fund has a total financing amount of USD 74.6 million [243]. Although dedicated regional energy resilience fund was not identified for Thailand, GCF financing could support the development of projects that address energy system resilience. In addition, multilateral development banks such as the Asian Development Bank (ADB) provide financing for energy and infrastructure projects that can indirectly address energy system resilience. For instance, ADB's partnership with Thailand prioritizes strengthening competitiveness, connectivity, and resilience, with total public sector loans, grants, and technical assistance commitments amounting to USD 7.4 billion in total as of 2024 [244].

3.20 United States

The United States has one of the world's largest and most complex power systems, organized into multiple large regional interconnections (Eastern, Western, Texas, etc.) and supplied by a diverse mix of thermal, nuclear and renewable generation in which natural gas and renewables have progressively displaced coal [245]. Operation is shared between Independent System Operators/Regional Transmission Organizations (ISO/RTOs) and vertically integrated utilities, while regulation of high-voltage transmission at the federal level falls to the Federal Energy Regulatory Commission (FERC) and technical reliability oversight to the North American Electric Reliability Corporation (NERC) [246,247]. Within this structure, energy resilience is understood not only as maintaining reliability in normal conditions, but as ensuring that the grid can withstand, adapt to and rapidly recover from major disturbances.

The main risks to resilience are linked to the increasing frequency and intensity of extreme weather events (hurricanes, wildfires, heat waves, winter storms), the growing threat of cyberattacks on industrial control systems, and vulnerabilities associated with ageing infrastructure, congestion and supply-chain disruptions [246,248,249]. The National Cybersecurity Strategy and the National Security Memorandum on Critical Infrastructure Security and Resilience (NSM-22) explicitly recognize energy as an enabling infrastructure for all other critical sectors and call for strengthening it against both physical and cyber threats [248,250]. In response, Congress passed the Infrastructure Investment and Jobs Act (IIJA, Public Law 117-58) in 2021, allocating more than USD 60 billion to energy-infrastructure programs, including targeted resources for grids, storage and system modernization [251]. Under this law, the Department of Energy (DOE) created the Grid Resilience and Innovation Partnerships (GRIP) program, with roughly USD 10.5 billion in competitive grants (including USD 2.5 billion for Grid Resilience Utility and Industry Grants, USD 3 billion for Smart Grid Grants, and USD 5 billion for the Grid Innovation Program) which provide direct funding to state and tribal governments to reduce the risk of outages from wildfires, storms and other disasters [251-256].

In the United States, funding for energy resilience mainly comes from federal infrastructure laws, disaster resilience programs, and targeted energy-sector initiatives, rather than from a single, dedicated resilience fund. In recent years, major federal actions have greatly increased investment to strengthen the electricity system against extreme weather, cyber threats, and other natural and man-made hazards. Through the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA), the federal government has committed more than USD 65 billion to power infrastructure, grid modernization, transmission expansion, and related resilience measures, including grid hardening and smart grid deployment [257, 258]. At the same time, the Department of Energy (DOE) runs dedicated programs such as the Grid Resilience and Innovation Partnerships (GRIP) and the Preventing Outages and Enhancing the Resilience of the Electric Grid (Section 40101) program to help states, utilities, and grid operators reduce outage risks and recover more quickly from disruptions. Additional federal disaster mitigation funding, including programs managed by FEMA, further supports the protection of critical energy infrastructure before and after extreme events [259]. Together, these funding streams strengthen the United States' ability to withstand disruptions, recover more quickly, and improve the electricity system over the long term [257–261].

Electricity distribution reliability in the United States is tracked using standard industry metrics that measure how long and how often customers lose power. According to the Electric Power Annual published by the U.S. Energy Information Administration, local reliability data for 2024 show that when all events, including major weather events, are counted, the SAIDI was about 401.9 minutes per customer per year, and the SAIFI was about 1.521 interruptions per customer per year. When major events are excluded, these values fall to roughly 126 minutes and 1.043

interruptions per customer per year, showing how strongly extreme events affect overall grid performance. These indicators, reported through EIA Form 861, provide a clear basis for assessing the resilience of the U.S. power distribution system and highlight the importance of continued investment and regulation to reduce outage impacts, especially as climate-related risks increase [262]..Core resilience policies combine technical regulation with large-scale investment. On the regulatory side, FERC approves the mandatory reliability standards developed by NERC and has directed NERC to incorporate extreme-weather, cybersecurity and supply-chain risks into these standards, complementing the traditional focus on reliability with a functional resilience perspective (prepare, absorb, adapt and recover) [246,247]. In parallel, DOE, through the Office of Cybersecurity, Energy Security, and Emergency Response (CESER), is tasked with coordinating the security and resilience of the energy sector against physical and cyber threats, acting as a focal point for collaboration with private operators and other federal agencies [248,249,263]. Among concrete program and success cases, the first GRIP funding rounds stand out for supporting smart-grid deployments, storage projects and critical line reinforcements across multiple states, while the Grid Resilience Formula Grants help modernize equipment, manage vegetation and harden infrastructure against wildfires and severe storms [252-255]. Government Accountability Office (GAO) reports have begun to assess the implementation of the cybersecurity and resilience strategy, noting advances in coordination and funding but also the need to strengthen performance measurement and integration across federal, state and local levels [249]. Overall, the United States addresses energy resilience through a robust legal framework (IIJA, NSM-22), mandatory FERC–NERC standards and major investment programs aimed at modernizing grids and enhancing the system's capacity to respond to climate- and cyber-related shocks [245,246,255,263].

3.21 Viet Nam

Viet Nam's power system is organized around a vertically integrated structure in which EVN holds the monopoly over electricity transmission and distribution, while sector policy is led by the Ministry of Industry and Trade (MOIT) through the Directorate General of Electricity and Renewable Energy, which is responsible for overall planning and energy policy [264]. According to the Institute of Energy of Viet Nam, electricity demand is expected to grow at around 12% per year to 2030, re-creating the risk of supply shortages similar to those experienced in 2023 if capacity additions and network reinforcements do not keep pace [264]. Against this background, Viet Nam aspires to a sustainable, smart and globally competitive energy sector by 2045. Resolution No. 70, issued in August 2025, sets out a roadmap to ensure local energy security through 2030 with a long-term vision to 2045, building on Resolution No. 55-NQ/TW of 2020, which established energy security as a central pillar of local security [265]. The new text adopts a more multidimensional and long-term approach, promoting a diversified portfolio with emphasis on renewables, Liquefied Natural Gas (LNG), hydrogen and modern nuclear energy, together with the development of strategic energy reserves and the modernization of transmission infrastructure using smart systems [265].

Climate change and extreme events add an additional layer of risk to Viet Nam's energy system. If adaptation and resilience measures are not incorporated, economic losses could reach up to 8.1% of GDP by 2050 under a severe climate scenario (RCP8.5), with direct implications for infrastructure and service reliability [266]. The roadmap for managing future climate impacts therefore considers a transition toward clean energy and affordable electricity that explicitly integrates mitigation and adaptation, incorporates permanent adjustments in operations and planning, seeks to avoid cascading effects on critical services during power interruptions and prioritizes diversification of the generation mix to reduce dependence on climate-vulnerable sources and improve overall system reliability [266]. In quantitative terms, EVN's Business Department head Nguyen Quoc Dung reported for 2024 a SAIFI of 1.95 interruptions per customer per year and a SAIDI of 199.83 minutes per customer per year, values that reflect the combined effect of rapid demand growth, network constraints and exposure to natural hazards [267]. The vulnerability of the grid to disasters is evident in events such as the floods of October and November 2025, which left more than 320 thousand customers without electricity and caused severe damage to network infrastructure in the affected areas [268]. Despite the approval of PDP8 and Resolution No. 55-NQ/TW (2020) that guides energy policy through 2045, investor confidence remains fragile due to regulatory uncertainty, inefficient permitting, and land-use mismatches that delay project implementation [269]. Major players like Samsung and Enel, who once announced plans to build 6 GW of renewable capacity, have expressed diminished confidence due to persistent grid constraints and a lack of regulatory clarity [270]. Meanwhile, USD 134 billion in investments will be needed by 2030 to meet PDP8 goals, but only a fraction, USD 15.5 billion, has been pledged through international initiatives like the G7 Just Energy Transition Partnership (JETP) [270].

Within this context, Viet Nam has begun to implement projects and policies with a clear resilience dimension. A flagship example is the economy´s first pumped-storage hydropower project at the Bac Ai power plant in Ninh Thuan province, signed in early 2025, with an investment of around USD 800,000 (VND 21,100 billion) and an installed capacity of 1,200 MW distributed across four 300-MW units, planned for the 2021–2030 period with a vision to 2050 [271]. This project is designed to provide large-scale storage to manage variability from renewables, enhance peak-load coverage, and increase the flexibility and robustness of the system in the face of demand surges or supply disruptions [271]. Taken together, the monopoly transmission and distribution role of EVN, MOIT's strategic steering through Resolution No. 70 and Resolution No. 55-NQ/TW, the explicit climate-risk assessments pointing to potential GDP losses, and large-scale storage investments such as Bac Ai show that Viet Nam is starting to connect energy security, decarbonization and climate adaptation under an emerging framework where resilience is gradually incorporated into planning, regulation and infrastructure development [264- 266,268,271].

4. Comparative Insights on Energy Resilience Across APEC Economies

This report has examined how energy resilience is addressed across a diverse set of APEC economies, from large interconnected systems to small island and archipelagic contexts. The economy by economy review shows that all members are facing a common structural shift. Their power systems must manage increasing climate and natural hazard risks at the same time that they expand renewable generation, modernize infrastructure and, in some cases, close access gaps. The following sections summarize the main common features that emerge from this comparison and highlight key differences that shape distinct resilience pathways.

4.1 Alignment across economies and with resilience definitions

APEC economies are compared based on their scope, meaning how they cover resilience aspects across different dimensions, and based on how they align with different resilience definitions. Table 2 was produced through a qualitative coding of each economy resilience assessment in this report against six resilience "scope" dimensions (in the context of resilience): climate and hazard risk, fuel and market security, cyber and digital, access and quality, energy planning and decarbonization, and cross sector or critical infrastructure. For each economy, a scope dimension is identified as positive (covered dimension) only when the policy documents and examples reviewed in the economy assessment refer explicitly to that dimension in the context of resilience being addressed or considered. Blank cells or dashes do not mean the economy is not acting in that area, only that the reviewed texts do not clearly frame it as a core resilience component. These dimensions were chosen because they are the minimal set of categories that covers the main resilience topics actually documented across the economy assessments in this report.

Table 3 was produced through an explicit mapping of each economy's resilience framing, as documented in the economy assessments, against the core elements of the resilience definitions used in the report (Table 1). Each economy was assessed independently against each definition and assigned a qualitative alignment level based on explicit overlap rather than inference (see Appendix A for details). The APEC column emphasizes the ability of energy systems to withstand extreme events, recover and return to normal conditions in a timely and efficient manner, build back better, secure stable supply, and reduce negative impacts on lives and economic activities. For IEA, higher alignment is assigned when resilience is framed around coping with hazardous events or structural trends while safeguarding security and reliability and supporting the clean energy transition. For CDRI, higher alignment requires resilience to be framed as a multi hazard, infrastructure system challenge linked to inclusive and sustainable development. For CIGRE, higher alignment is assigned when power system resilience is framed in terms of limiting the extent, severity, and duration of degradation through planning, operational practices, and recovery measures.

Table 2 Comparison across APEC economies. (✓*: Not clear classification)

Economy	Climate and hazard risk	Fuel and market security	Cyber and digital	Access and quality	Energy Planning and decarbonization	Cross-sector or critical infrastructure
Australia	✓	✓	✓	✓	✓	✓
Brunei Darussalam	✓	✓	–	–	✓	–
Canada	✓	✓	✓	✓	✓	✓
Chile	✓	✓	–	✓	–	–
People’s Republic of China	✓	✓	–	✓	✓	–
Hong Kong, China	✓	✓	–	–	✓	–
Indonesia	✓	✓	–	✓	–	–
Japan	✓	✓	✓	✓	✓	–
Republic of Korea	✓	✓	–	–	✓	✓*
Malaysia	✓	✓	–	✓	✓	✓
Mexico	✓	✓	–	✓	✓	–
New Zealand	✓	✓	–	✓	✓	✓
Papua New Guinea	✓	–	–	✓	–	–
Peru	✓	–	–	✓	–	–
The Republic of the Philippines	✓	✓	–	✓	–	–
The Russian Federation	✓	✓	–	✓	✓	✓
Singapore	✓*	✓	✓	✓	–	–
Chinese Taipei	✓	✓	–	–	✓	–
Thailand	✓	–	–	–	–	–
United States	✓	✓	✓	✓	✓	✓
Viet Nam	✓	✓	–	✓	✓	✓

Table 3 Alignment with resilience concepts

Economy	Alignment with APEC	Alignment with IEA	Alignment with CDRI	Alignment with CIGRE
Australia	High	High	High	High
Brunei Darussalam	Medium	Medium/High	Medium	Low/Medium
Canada	High	High	High	High
Chile	Medium/High	High	Medium	High
People's Republic of China	Medium/High	Medium/High	High	High
Hong Kong, China	Medium/High	High	Medium/High	Medium/High
Indonesia	Medium/High	High	High	High
Japan	High	High	High	High
Republic of Korea	Medium/High	High	Medium/High	Medium
Malaysia	High	High	High	High
Mexico	High	High	High	High
New Zealand	High	High	High	High
Papua New Guinea	Low/Medium	Low/Medium	Medium	Medium
Peru	Medium/High	Medium/High	Medium/High	High
The Republic of the Philippines	High	High	High	High
The Russian Federation	High	High	High	High
Singapore	High	High	High	High
Chinese Taipei	Medium/High	High	Medium	Medium/High
Thailand	Medium	Medium	Medium	Medium
United States	High	High	High	High
Viet Nam	High	High	High	High

4.2 Common features across APEC economies

Across the region, climate and natural hazards are a shared and growing source of stress for power systems. The specific mix of hazards differs by economy, but mostly every case documents exposure to events such as floods, storms, droughts, wildfires, landslides, heat waves, sea level rise, or seismic risks that can affect generation plants, transmission corridors, and distribution networks. In Chile, the long-running megadrought has reduced river flows and constrained hydropower, while heat waves in the central-southern zone and related forest fires have pushed infrastructure into emergency operating conditions. In Canada, climate change is increasing wildfire and flood risks to energy infrastructure, and the report notes that annual damage costs could reach CAD 4.1 billion without resilience investments, with major fires in 2023 also forcing shut-ins of oil and gas production. In the Philippines, around twenty typhoons per year have contributed to cumulative reconstruction claims by electric cooperatives and substantial losses in distribution assets. Thailand and Viet Nam report severe floods and storms that disrupt lines and substations, while Japan and Chinese Taipei face compounded risks from earthquakes, tsunamis, typhoons, and landslides affecting coastal and mountainous infrastructure.

Resilience is present in policy and regulation across APEC, even when it is not always labeled as “energy resilience.” Many economies have climate framework laws, adaptation plans, disaster resilience strategies, or energy security principles that recognize electricity as critical infrastructure and assign responsibilities to energy authorities and system operators. Examples discussed in the report include Chile’s climate framework law and energy sectoral plan, Peru’s climate change framework law and adaptation planning, Mexico’s climate change law and program instruments, and Russia’s energy security doctrine and climate adaptation planning. Similar roles are reflected in New Zealand’s local resilience and adaptation planning, Japan’s local resilience planning, Canada’s local adaptation strategy, and the United States federal approach combining infrastructure policy with critical infrastructure directives. In other cases, resilience is framed through long-term energy strategies and security-focused planning, such as Indonesia’s local energy policy and planning instruments or Malaysia’s energy transition roadmap.

A related common feature is that resilience measures are increasingly linked to investment planning and financing, even though dedicated “energy resilience funds” are not always identified. The report shows several recurring approaches, including regulated utility investment programs, public co-funding through local infrastructure and energy programs, and climate finance where applicable. Examples in the report include targeted public programs supporting grid resilience in the United States, climate finance support referenced for Thailand, and grant-based support for innovation and system modernization discussed for Singapore. These financing approaches also reflect a broader trend in the assessments as economies often justify resilience actions through avoided outage costs, avoided infrastructure damage, and reduced recovery burdens following extreme events.

A further common feature is the widespread use of technical indicators and standards to monitor reliability and, indirectly, resilience. Most economies track the frequency and duration of interruptions through SAIFI and SAIDI and use technical codes to govern planning and operation. At the same time, the report highlights an opportunity to develop resilience-oriented performance metrics that go beyond standard power reliability indicators and reflect broader energy system outcomes under extreme events. Examples in the report include Australia's Unserved Energy standard and customer-level indicators, Canada's reporting of transmission and distribution reliability indicators and development of standards, Chile's tracking of household SAIDI and application of quality and security standards, and economy-specific quality regulation in Mexico and Peru. Hong Kong, China and the Republic of Korea report very low outage indicators that are comparable to the best performing systems worldwide. Taken together, these examples show that APEC economies already share a common language for continuity of supply, even if resilience to extreme events is not fully captured by existing reliability metrics.

Decarbonization and energy transition targets are another strong common thread. Rapid renewable deployment without adequate flexibility can introduce new vulnerabilities, including higher dependence on weather-driven resources, sharper ramps, periods of very low or very high net load, and tighter operating margins if conventional plants retire faster than system services such as inertia and reserves are replaced. In this context, almost every assessed economy has a net-zero or carbon neutrality goal and policies that support renewables, efficiency, or other low-carbon technologies. The report highlights New Zealand's high share of renewable electricity and its efforts to manage dry-year risk, Chile's rapid expansion of renewables alongside coal retirement planning, and Canada's electricity decarbonization progress alongside major investments to extend the life of its nuclear fleet. In Southeast Asia, the report notes that Indonesia; Malaysia; Thailand; and Viet Nam are expanding renewable and cleaner energy strategies while fossil fuels still dominate primary energy in many cases. Nuclear power remains an important low-carbon source in several economies, and the report notes that it is also being considered as a future option in Singapore and Viet Nam.

Finally, many economies are converging on similar technical solutions to support resilience. Digitalization and advanced control systems are becoming increasingly important, although Table 4.1 shows that cyber and digital resilience is still addressed explicitly in only a subset of the assessed economies. The report highlights examples such as Singapore's work on data platforms and advanced system tools, Hong Kong, China's monitoring and analytics capability to anticipate faults and environmental threats, and Indonesia's I-ENET program supporting distribution modernization and digital operations. The report also discusses grid-scale storage and system reinforcement efforts, including Australia's Waratah Super Battery operating as a virtual transmission asset and planning work that considers delivery constraints for infrastructure. Storage, microgrids, and distributed resources referenced in several economy assessments further illustrate how flexibility and decentralization are increasingly viewed as resilience assets.

4.3 Key differences in system resilience approaches across APEC economies

Beyond shared regional trends, resilience challenges vary significantly across APEC economies because power systems are at very different stages of development, access, and reliability. In economies such as Australia; Canada; Chile; Hong Kong, China; Japan; the Republic of Korea; Malaysia; Mexico; New Zealand; Singapore; Chinese Taipei; and the United States, electricity access is already near universal and systems are large and often interconnected, with established markets or regulatory frameworks. In these settings, the resilience agenda tends to focus on strengthening aging infrastructure, managing escalating risks from extreme weather, and integrating higher shares of variable renewables while avoiding large-scale outages. Recent events underscore that high access does not guarantee high resilience. The economy-wide blackout in Chile in February 2025 exposed weaknesses in 500 kilovolt transmission planning and protection and led to regulatory investigations and fines. The large disturbance in Mexico at the end of 2020, which temporarily left more than ten million users without power, highlighted the need for robust automatic protection schemes and coordinated action between CENACE and CFE to contain cascading effects. Cyber and digital risks are increasingly relevant in these more digitalized systems, but the report evidence shows that explicit cyber resilience measures are not covered uniformly across all economies.

In other APEC economies, resilience cannot be separated from the basic access and quality agenda. Papua New Guinea, for example, still has only around 20 percent access, with even lower levels in rural areas. The report highlights the World Bank–supported NEAT project, which aims to expand access through a mix of grid extension, microgrids, and solar home systems, with a target of roughly 70 percent electrification by 2030. In these contexts, the resilience of new connections to climate and disaster risks is as important as the connections themselves. Similar, though less extreme, patterns appear in Peru, where quality standards permit far higher interruption frequency and duration in rural systems than in Lima, and in the Philippines, where system averages can mask very weak performance and repeated reconstruction needs among remote electric cooperatives. These access-oriented systems also face a distinct financing challenge. Expansion and resilience upgrades often rely on concessional finance, grants, or externally supported programs, and cost recovery can be constrained by affordability. As a result, planning decisions about whether to extend the main grid into remote, hazard-prone areas or prioritize decentralized solutions need to be made explicitly through a resilience lens, with a clear view of life-cycle costs, recovery burdens, and the feasibility of maintaining service after extreme events.

A second major difference is the structure of generation mixes and the stage of the energy transition. Some economies have electricity systems already dominated by hydropower and other renewables. New Zealand's power supply depends heavily on hydropower and is therefore sensitive to dry-year conditions, which the report notes the government seeks to address through the New Zealand Battery Project and careful management of thermal backup. Parts of Canada; Chile; and Peru also rely strongly on hydropower, with growing contributions from wind and solar. This introduces both exposure in water resources and operational challenges in balancing variable output. In these systems, resilience strategies need to prioritize hydrological risk management, storage, interconnection, and flexible demand while maintaining low emissions.

Other economies remain anchored in fossil fuels, especially coal and natural gas, even as renewables expand. The report notes, for example, that Indonesia still generates most of its electricity from coal and has renewable targets of at least 23 percent in 2025 and 31 percent in 2050, while updating its RUPTL to increase the share of renewable capacity in planned additions. Malaysia's primary energy supply remains dominated by natural gas, petroleum products, and coal, with renewables below 5 percent in 2020, and its transition roadmap projects gas remaining above half of total primary energy in 2050 as coal declines toward zero. Thailand's plans call for renewables to reach 30 percent of the mix by 2037 with no new coal-fired plants. Viet Nam is expanding renewables in a system that has recently experienced supply shortages and outages, including disruptions in 2023, and is planning new pumped storage capacity at Bac Ai. In these economies, resilience is closely tied to secure and affordable fuel supplies, long-term diversification, and renewable integration strategies that avoid widespread curtailment and local reliability problems, including cases where renewable capacity expands faster than grid reinforcement. These challenges can be compounded by disruptions to fossil fuel supply chains from extreme weather events and geopolitical tensions, which can interrupt production, transport, and imports and expose dependence on a limited set of fuels or suppliers.

Resilience is also shaped by differences in governance arrangements and market structures, including how investment is planned, financed, and implemented. In economies with liberalized or partially liberalized markets and independent system operators, resilience is increasingly treated as an explicit planning and investment objective. The report highlights the United States model of regional transmission organizations and vertically integrated utilities operating under federal reliability standards, alongside substantial public funding channels for resilience, including the Grid Resilience and Innovation Partnerships and formula grants. Australia's National Electricity Market is guided by AEMO's Integrated System Plan, which defines an optimal development path for net zero while explicitly addressing security and resilience needs. New Zealand's wholesale market relies on Transpower not only to operate the grid but also to lead future security and resilience work. Mexico organizes system operation through CENACE and is transitioning from PRODESEN to a new electricity sector development plan, which will shape how resilience is embedded in planning going forward. In economies relying on integrated state-owned utilities, resilience is often embedded directly in local plans and utility investment programs rather than being driven by market signals. The report points to examples such as PLN in Indonesia; EVN in Viet Nam; Taipower in Chinese Taipei; KEPCO in the Republic of Korea; and the integrated fuel and energy complex in Russia. These models can provide a clear mandate for resilience through strategic documents, but outcomes depend heavily on the financial health and technical capacity of dominant entities, the stability of public budgets, and the ability to prioritize resilience alongside other policy and commercial objectives. The report's Russia assessment illustrates this model through resilience financing embedded in state programs and regulated investment mechanisms under long-term strategic planning.

There are also important differences in how explicitly the concept of resilience is used. Some economies, such as Australia; Chile; Japan; New Zealand; the Philippines; Singapore; and the United States, use resilience as an organizing principle for energy and infrastructure policy. The report notes Japan's Act for Establishing Energy Supply Resilience and related requirements for disaster cooperation planning and emergency coordination. It also highlights the Philippines' use of Resiliency Compliance Plans and assessment tools to evaluate preparedness of facilities. Australia's system planning explicitly defines energy resilience in planning and risk assessments, and Singapore frames resilience as a flexible and adaptive power system supported by diversified supply and advanced digital tools. In other economies, resilience is primarily expressed through traditional concepts such as energy security, reliability, and climate adaptation, even where the practical building blocks overlap. This difference does not prevent action, but it can limit coordination across institutions and reduce the clarity of accountability under a shared strategic vision.

These differences reinforce the value of APEC as a platform for practical peer learning. High-renewable systems can share lessons on managing hydrological variability and dry-year risk with economies planning rapid renewable scale-up. Economies that have implemented major storage initiatives, including pumped storage planning and battery-based solutions highlighted in several assessments, can share implementation lessons on procurement, grid integration, and operating practices. Island and city systems such as Hong Kong, China; Singapore; and Chinese Taipei can provide insights on balancing import dependence, LNG flexibility, storage, and distributed resources. Economies with strong regulatory and market frameworks can share experience on reliability standards, resilience funding design, and performance-oriented incentives. At the same time, economies using resilience planning to address access gaps, such as Papua New Guinea; and parts of Indonesia and the Philippines, can contribute lessons on designing decentralized and community-based solutions that remain robust under severe local hazards and financing constraints.

5. Main Findings and Policy Recommendations

APEC energy systems now operate at the intersection of rapidly growing electricity demand, intensifying climate and disaster risks, expanding digitalization, and evolving energy markets. Across the economies reviewed, resilience is no longer treated as a narrow technical issue. It is increasingly recognized as a core energy policy objective needed to protect social and economic stability and to support credible decarbonization pathways. The analysis also shows that many resilience technologies and operational solutions are available and mature, but their deployment depends mainly on governance factors such as policy design, regulatory requirements, planning standards, and institutional capacity.

A first main finding is that economies converge around the central idea of resilience as the ability of energy systems to withstand shocks, maintain essential services, and recover in a timely manner. At the same time, the evidence in this report shows that the operational scope and coverage of resilience still differ significantly across economies. Many economy assessments reflect a broad framing that connects resilience with climate adaptation, energy security, transition planning, and continuity of essential services. However, Table 4.1 indicates that explicit treatment of cyber and digital resilience and cross sector or critical infrastructure interdependencies appears in only a subset of economies. In other words, broad resilience framing is increasingly present across the region, but explicit coverage of cyber risks and interdependency management remains uneven. This difference matters because these dimensions are becoming more material as systems digitalize and as disruptions increasingly propagate through fuel logistics, telecommunications, transport, and other lifeline infrastructures.

A second finding is that progress on diagnostics, metrics, and planning is uneven. Several economies apply multi-hazard risk assessments, climate impact studies for critical assets, and explicit resilience requirements in planning instruments, grid codes, and regulatory standards. Other economies rely on high-level strategies with limited binding obligations, and hazard and climate scenario information is not consistently integrated into investment decisions. In addition, most economies track reliability through SAIDI and SAIFI and use standards and technical codes to guide system performance. These indicators provide a common language for continuity of supply, but they do not fully capture resilience to extreme events or broader energy system impacts beyond the power sector. The report therefore highlights a clear opportunity for APEC economies to strengthen resilience measurement by complementing traditional reliability indicators with metrics that reflect preparedness, recovery speed, service to critical loads, fuel and supply chain robustness, cyber readiness, and systemwide outcomes under stress.

A third finding is that differences in system development and service quality shape distinct resilience priorities. Economies with large, interconnected systems and near-universal access focus on strengthening aging infrastructure, managing escalating extreme weather risks, integrating high shares of variable renewables while maintaining system security, and addressing emerging digital vulnerabilities. Recent events in the region also confirm that high access does not guarantee high resilience. By contrast, in economies with low electrification rates or large urban–rural quality gaps, resilience cannot be separated from the access agenda. Choices about extending the main grid into remote, hazard-prone areas versus prioritizing decentralized solutions influence not only who receives electricity, but also how robust that supply will be under local climate and disaster risks. These contexts also tend to face greater constraints on cost recovery and financing, which affects the feasibility of sustaining resilient service over the full life cycle of infrastructure.

A fourth finding concerns the stage of the energy transition and exposure from generation and fuel structures. Economies anchored in coal, gas, and oil remain exposed to fuel supply chain disruptions, price volatility, and import risks, including disruptions from extreme weather events and geopolitical conditions. At the same time, rapid renewable deployment without adequate investment in flexibility, storage, transmission reinforcement, and system services can create new vulnerabilities, including sharper ramps, tighter operating margins, congestion, and curtailment. In both cases, resilience and decarbonization need to be managed together so that pathways to lower emissions do not inadvertently increase exposure to weather-dependent resources, single critical corridors, or external fuel shocks.

A fifth finding is that governance and market structure influence how resilience is planned, financed, and implemented. Economies with liberalized or partially liberalized markets and independent system operators increasingly treat resilience as an explicit planning and investment objective, supported by dedicated regulatory mechanisms and, in some cases, public funding. Economies with integrated state-owned utilities often embed resilience in local strategies and utility investment programs, supported by central mandates through long-term plans and energy security doctrines. Both models can deliver strong outcomes, but both face implementation risks. Market systems must align incentives and clarify responsibilities across institutions. Vertically integrated systems depend heavily on the financial health, technical capacity, and budget stability of dominant entities to deliver sustained resilience investments.

Finally, the mapping of each economy's resilience framing against reference definitions indicates areas of strength and gaps. Several economies show broad alignment with multiple resilience concepts, combining hazard and climate risk management, secure and affordable supply, detailed grid resilience measures, and transition-related flexibility. Others align strongly with more technical, power-system-focused concepts but are less explicit on cyber and digital risks, cross sector dependencies, and broader development or equity considerations. Access-constrained and hazard-exposed economies often emphasize resilience in ways closely linked to development and service continuity but may still be strengthening the links between resilience, long-term climate goals, and energy transition planning. These differences reinforce the value of APEC cooperation and guidance to help economies translate broad resilience aspirations into more comprehensive and measurable coverage, including cyber and interdependency dimensions that remain uneven across the region.

5.1 Policy recommendations

- APEC economies would benefit from adopting clearer, more comparable energy resilience concepts in policy and planning, and from translating those concepts into operational requirements. While the report finds convergence around the general idea of withstanding disruptions and recovering quickly, economies still apply different scopes and terms, which can limit coordination across agencies and weaken the investment case for resilience. A practical step is to adopt an explicit resilience definition in energy policy documents that is consistent with the APEC energy resiliency framing and to embed that definition in planning standards, grid codes, and utility obligations. This should clarify that resilience is not limited to routine reliability, and it should specify minimum expectations across preparedness, withstanding impacts, recovery performance, and "building back better" where relevant.
- APEC economies have a clear opportunity to strengthen energy resilience through regional cooperation that improves consistency in definitions, financing approaches, and operational practices, particularly for high-impact climate and disaster shocks. Building on the shared resilience concepts identified in this report, economies could work together to establish practical cooperation mechanisms such as joint stress-testing and emergency response exercises, mutual assistance arrangements for restoration and repair, shared outage and hazard data frameworks, and greater interoperability of standards and planning methodologies. Where cross-border interconnections and shared corridors are relevant, economies could also coordinate protection philosophies, restoration protocols, and adequacy planning to reduce the risk of cascading impacts and to accelerate recovery following major disruptions. This regional approach would reinforce APEC's value as a platform for peer learning and implementation support while helping economies translate resilience goals into measurable, financeable actions.
- Financing and cost effectiveness should be treated as central enablers of resilience. The report highlights that resilience investments reduce outage costs, infrastructure damage, and recovery burdens, and international experience often supports cost-benefit ratios on the order of four to one for well-designed measures. Economies should strengthen the economic case for resilience by requiring structured cost-benefit assessment for major investments, including avoided outage costs, avoided repair and replacement costs, and avoided social and economic disruption. Implementation should also be supported by clear financing pathways, which may include regulated resilience investment frameworks for networks, targeted public programs and grants for priority upgrades, and blended finance where appropriate. In access expansion contexts, financing approaches should explicitly include long-term operation and maintenance so that new connections remain reliable and resilient over time.

- APEC economies should improve resilience metrics beyond traditional reliability indicators. SAIDI and SAIFI remain essential and are widely used, but they do not fully capture preparedness, performance during extreme events, or the ability to sustain critical services, and they do not reflect energy system impacts beyond electricity. Economies should complement SAIDI and SAIFI with a small set of practical measures that can be reported consistently, such as restoration time after major events, performance for critical facilities and essential services, and indicators of exposure and redundancy for critical corridors. Where fuel supply chains are central to system resilience, metrics should also capture basic fuel security performance, such as diversification, storage adequacy, and logistics vulnerability under stress. APEC can support this by developing voluntary regional guidance on a core resilience metrics package and reporting practices that improve comparability while remaining feasible for different system contexts.
- Policy actions should also be tailored to differences in system maturity and service conditions identified across the economy assessments. In access and quality constrained economies, resilience policy should be integrated into electrification planning and quality improvement. This includes applying a resilience lens to choices between grid extension and decentralized solutions in remote, hazard-prone areas, adopting minimum climate-resilient design standards for new infrastructure, and ensuring that tariff design, subsidies, or program funding can support sustainable operation and maintenance. In mature systems with near-universal access, policy should prioritize modernization of aging assets, hardening and redundancy for critical corridors, disturbance prevention and containment through robust protection schemes and operational protocols, and planning for increasing exposure to extreme weather as the generation mix changes.
- Fuel and market security should be addressed explicitly as a resilience pillar, reflecting its prominence across the economy assessments. For economies with significant dependence on fossil fuels, imports, or limited suppliers, resilience planning should include stress testing for fuel disruption and price shocks, diversification strategies, and measures to strengthen storage and logistics. As economies transition, fuel security should be managed alongside decarbonization to avoid replacing one form of dependence with another, and to ensure that reliability and affordability are maintained during periods of rapid system change.
- Cross-sector interdependencies should be incorporated more systematically where they influence energy resilience outcomes. The report shows that some economies explicitly address links between electricity and other critical infrastructures, while others treat these connections indirectly. Economies would benefit from mapping dependencies among electricity, fuel supply chains, telecommunications, transport, and water systems, and from establishing coordinated emergency protocols and restoration priorities for essential services. APEC can add value by sharing practical approaches to critical infrastructure coordination that can be adapted to different institutional settings.

Several enabling actions are consistently relevant across the region. Economies should integrate multi-hazard and climate risk information into energy planning and investment decisions, including compound events and long duration stressors such as drought. They should strengthen institutional coordination and clarify roles across ministries, regulators, system operators, and utilities, including emergency response arrangements and restoration practices. They should ensure that renewable integration strategies include adequate flexibility through storage, demand-side measures, transmission reinforcement, and system services, so decarbonization does not increase vulnerability. They should also address cyber and digital resilience more systematically, recognizing that digitalization is accelerating but is not covered consistently across economies. APEC can support implementation through practical peer learning focused on solutions already being deployed in the region, including grid modernization, storage, decentralized systems for remote areas, and planning approaches that embed resilience as an explicit objective.

6. APEC Workshop Summary Report

As part of the APEC project Building Resilient Energy Policies in Asia-Pacific (EWG_104_2024A), this international workshop was held on 27–28 October 2025 in Santiago, Chile. The event convened representatives from APEC member economies to examine how climate resilience can be systematically integrated into energy policy formulation, regulatory planning and long-term investment strategies. Discussions focused on the increasing exposure of energy systems to climate-related disruptions, the need to strengthen institutional coordination, and the methodological challenges associated with measuring and operationalizing resilience. Over two days, participants engaged in keynote presentations, panel exchanges, and case-based dialogue to review current policy tools, identify regulatory gaps, and assess disaster risk screening practices. The workshop enabled APEC economies to share experiences on climate-risk governance, financing mechanisms and resilient infrastructure planning, generating technical insights that will support the development of robust, adaptive and secure energy policies across the Asia-Pacific economies.

6.1 Agenda

The workshop opened with remarks from the Ministry of Energy of Chile, followed by a presentation of the project objectives and a keynote session led by the International Energy Agency on global trends in climate resilience for energy security. Day 1 examined resilience planning in the energy transition, including system flexibility insights from Chile's decarbonization strategy and Thailand's renewable adaptation pathways, as well as resilient power system planning in Latin America and climate disaster risk implications for critical infrastructure.

In the afternoon of the first day, the focus shifted to hazard assessment and institutional coordination. Contributions from SENAPRED, the Coalition for Disaster Resilient Infrastructure, and the Ministry of Energy of Chile addressed multi-hazard diagnostics, risk governance, and practical mechanisms for integrating resilience into energy planning. The day concluded with a regional panel discussion on how ministries, regulators, and system operators can jointly strengthen preparedness and emergency response in the energy sector.

On Day 2, the agenda turned to allowing conditions for resilient investment, exploring financing instruments, investment barriers, and strategic pathways for strengthening energy infrastructure. Presentations from InvestChile, the Coalition for Disaster Resilient Infrastructure, and Transelec highlighted the role of finance, private sector engagement, and operational challenges in modernizing grid assets under climate stress. The workshop closed with applied case studies, a synthesis of key messages from both days; emphasizing the need to integrate risk diagnostics, climate adaptation, and investment planning into energy policy; and the closing remarks by the Ministry of Energy of Chile.

Day 1

Asia-Pacific Economic Cooperation

Ministerio de Energía

Gobierno de Chile

BUILDING RESILIENT ENERGY POLICIES IN ASIA PACIFIC

DAY 1

08:30 - 9:00	**Registration and welcome coffee**
09:00 - 9:10	**Welcome Remarks: Mr. Luis Felipe Ramos | Undersecretary of the Ministry of Energy of Chile**
09:10 - 9:20	**Welcome Remarks: Ms. Alicia Cebrián | SENAPRED Director and EPWG APEC Co-Chair (tbc)**
09:20 - 9:40	**Project Summary and Objectives** Ph.D Felipe Feijoo | Researcher | Pontificia Universidad Católica de Valparaíso

TOPIC 1 BUILDING AND PLANNING RESILIENCE IN THE ENERGY TRANSITION

09:40 - 10:10	**Keynote: Climate Resilience for Energy Security: Global Trends and Regional Implications** Ms. Julie Dallard | **International Energy Agency**
10:10 - 10:40	**Resilience and Flexibility in a Renewable Future: Insights from Chile's Decarbonization Plan** Ms. Isabella Villanueva | Head of Planning and Climate Change Unit | **Ministry of Energy of Chile**
10:40 - 11:10	**Thailand's Path to Energy Resilience: Leveraging Renewable Energy Policies for Climate Adaptation** Ph.D Yaowateera Achawangkul | Department of Alternative Energy Development and Efficiency | **Ministry of Energy of Thailand**
11:10 - 11:40	**Resilience Integration in the Chilean Long Term Energy Planning Process** Ph.D Matías Paredes | Planning and Climate Change Unit | **Ministry of Energy of Chile**
11:40 - 12:10	**Methodological Study for Resilient Power-System Planning in Latin America and the Caribbean** Mr. Andrés Pereira | **CEPAL Consultant**

Free Lunch break

TOPIC 2 RISK AND HAZARD ASSESSMENT

14:00 - 14:30	**Keynote: Energy Infrastructure under Climate and Disaster Risk** Mr. Aaron Schubert | Director | **Coalition for Disaster Resilient Infraestructure**
14:30 - 15:00	**Disaster Risk Reduction: Foundations, Practical Insights, and Recent Advances from SENAPRED** Mr. Juan Piedra | Head of Planning for Disaster Risk Management | **SENAPRED**
15:00 - 15:30	**Advancing Towards Disaster-Resilient Energy Infrastructure** Mr. Joan Romero | Head of the Resilience and Risk Management Unit | **Ministry of Energy of Chile**
15:30 - 16:10	**Panel Discussion: Building Resilience in Energy Systems: Global and Regional Perspectives** **Moderator:** Ms. Isabella Villanueva | Head of Planning and Climate Change Unit | **Ministry of Energy of Chile** **Panelists**: • Ms. Julie Dallard | **International Energy Agency** • Mr. Aaron Schubert | Director | **Coalition for Disaster Resilient Infraestructure** • Ph.D Yaowateera Achawangkul | Department of Alternative Energy Development and Efficiency | **Ministry of Energy of Thailand**
16:10 - 17:10	**Networking Coffee**

Day 2

BUILDING RESILIENT ENERGY POLICIES IN ASIA PACIFIC

DAY 2

08:30 - 9:00 **Registration and welcome coffee**

09:00 - 9:15 **Summary of Day 1 and Day 2 Objectives**
Ph.D Felipe Feijoo| Researcher | **Pontificia Universidad Católica de Valparaíso**

TOPIC 3 UNLOCKING INVESTMENT AND OVERCOMING BARRIERS

09:15 - 09:45 **Keynote: Scaling up Investments in Resilient and Sustainable Energy Infrastructure: Investment opportunities**
Ms. Camila Vivanco | **InvestChile**

09:45 - 10:15 **Financing Resilient Energy Infrastructure**
Mr. Amit Tripathi | Power Sector Advisor | **Coalition for Disaster Resilient Infrastructure**

10:15 - 10:45 **Advancing Energy Resilience in Chile: Key Pathways and Strategies**
Mr. Jorge Moreno | **Inodú**

10:45 - 11:45 **Panel Discussion: Scaling up Resilient Energy Infrastructure: Strategic Perspectives**
Moderator: Ms. Adelaida Baeriswyl | International Relations Coordinator | **Ministry of Energy of Chile**
Panelists:

- Ms. Camila Vivanco | **InvestChile**
- Mr. Amit Tripathi | Power Sector Advisor | **Coalition for Disaster Resilient Infrastructure**
- Mr. Jorge Moreno | **Inodú**

TOPIC 4 FROM THEORY TO PRACTICE: CASE STUDIES AND BEST PRACTICES

11:45 - 12:15 **Keynote: Energy Resilience Assessments: Exploring Regional and Country Profiles**
Mr. Victor Garcia Tapia | **International Energy Agency**

12:15 - 12:45 **Transelec: Challenges Associated with Resilience**
Mr. Eduardo Zamora | Head of Electric Systems| **Transelec**

12:45 - 13:00 **Summary of Day 1 and Day 2**
Ph.D Felipe Feijoo| Researcher | **Pontificia Universidad Católica de Valparaíso**

13:00 - 13:15 **Closing Remarks**
Ms. Isabella Villanueva | Head of Planning and Climate Change Unit | **Ministry of Energy of Chile**

6.1.1 Day 1: Summary of Day 1: Global Frameworks, Local Pathways, and Integrated Resilience Planning

Day 1 provided a structured examination of how APEC economies are integrating climate resilience into energy security strategies, highlighting shared systemic pressures and the accelerating role of climate-driven disruptions. Opening presentations from the IEA and CDRI underscored that more than 85% of power outages in 2023 were caused by weather-related hazards and that global losses now exceed USD 700 billion annually, reinforcing the economic and strategic rationale for resilience investments.

1. The first topic block emphasized global trends in infrastructure adaptation, early-warning systems, and distributed energy solutions, positioning resilience not only as an engineering concern but as a pillar of energy security. Presenters stressed that coordinated planning, rapid recovery protocols, and the deployment of microgrids, storage and distributed generation are becoming essential tools for shock absorption and continuity of supply.
2. The second topic block focused on regional policy pathways. Chile outlined its decarbonization roadmap, targeting more than 80% renewable generation and a zero-emission power system by 2050, supported by strengthened transmission and flexibility measures. Thailand presented its carbon-neutrality target for 2050 and net-zero commitment by 2065, structured under the "4D1E" strategy, which connects digitalization, decarbonization and decentralized community systems.
3. A dedicated session examined how resilience is being embedded into planning and regulatory frameworks. Chile's long-term planning methodology (PELP) and ECLAC's regional study demonstrated how risk metrics, vulnerability proxies and recovery capacities can be incorporated into 30-year expansion modelling.
4. This was complemented by discussions led by SENAPRED and disaster-risk specialists, who highlighted the institutional evolution toward integrated risk governance and the local roadmap for resilience under the MoU between MOE, SENAPRED and CDRI.

In summary: Day 1 advanced a shared understanding that resilience is no longer a complementary dimension of energy policy but a structuring principle of security and decarbonization. Economies signaled convergence toward climate-risk integration, improved emergency coordination, modernized transmission systems, and expanded distributed resources, while also recognizing the need for common methodologies to quantify resilience and accelerate regional learning within APEC.

6.1.2 Day 2: Financing, Planning, and Implementing Resilient Energy Systems

The second day focused on translating resilience planning into concrete implementation pathways, emphasizing financing mechanisms, infrastructure modernization, regulatory consistency, and climate-risk integration across the energy sector. Sessions highlighted how APEC economies are moving from diagnosing vulnerabilities to executing measures that strengthen electricity systems in the face of increasing climate, hydrological and operational stress. The agenda combined perspectives from InvestChile, CDRI, the IEA, SENAPRED, and Inodú, alongside a multi-stakeholder discussion on how to mobilize resilient investment and operational standards.

1. **Resilient Investments and Financing Readiness:** InvestChile outlined the investment barriers and opportunities posed by climate-driven disruptions, noting that grid reinforcement, energy storage and adaptation-oriented retrofits are beginning to be prioritized in investor pipelines. CDRI presented the Global Infrastructure Resilience Initiative (GIRI) as a tool to align risk modelling, technical design and funding criteria, stressing that resilient infrastructure requires lifecycle financial planning rather than post-event funding.
2. **From Risk Diagnosis to Operational Practice:** The IEA detailed local vulnerability profiles and resilience assessment frameworks, showing how economy-specific exposure, such as wildfires in Chile, cyclones in Philippines, hydrological variability in New Zealand and rapid demand growth in Viet Nam, requires tailored methodologies rather than uniform standards. Inodú reinforced this with recent Chilean blackout and extreme-weather evidence, illustrating how restoration capability, vegetation management in transmission corridors, and blackout-restart protocols determine real-world resilience beyond regulatory definitions.
3. **Institutional Coordination and Emergency Preparedness:** SENAPRED emphasized that electric infrastructure must be integrated into local disaster management systems, not treated as a parallel operational domain. The panel concluded that inter-institutional coordination remains a critical weakness across APEC economies, particularly during compound climate events. Economies highlighted the importance of continuing to build joint response protocols, interoperable data platforms and harmonized restoration procedures between operators, energy ministries, regulators and emergency agencies.

In summary: Day 2 underscored that achieving resilience requires alignment between financing, emergency governance and infrastructure planning. Presentations converged on the need for stronger investment signals, hazard-based planning requirements, and operational coordination across institutions. The workshop demonstrated that APEC economies share structural challenges—aging grids, increasing climate exposure, and growing renewable penetration—and that advancing resilience will depend on implementation frameworks that mobilize capital, strengthen restoration capacity and institutionalize climate-risk management across the energy system.

6.1.3 Speakers

The workshop was supported by 13 speakers from important institutions across government, international organisations and the private sector. This diverse group, including representatives from the International Energy Agency, APEC economies such as Chile and Thailand, regional organisations and industry, enabled a comprehensive discussion on how to build resilient energy policies in the Asia-Pacific region. The speakers talked about climate and disaster risk assessment, long-term planning of power systems, regulatory and institutional frameworks, and investment strategies for resilient infrastructure. These perspectives highlighted the importance of integrating risk management, flexibility and resilience considerations into energy policy and planning. Below is a brief introduction to each of the speakers.

- **Julie Dallard**: International Energy Agency
- **Isabella Villanueva:** Head of Planning and Climate Change Unit | Ministry of Energy of Chile
- **Yaowateera Achawangkul:** Department of Alternative Energy Development and Efficiency| Ministry of Energy of Thailand
- **Matías Paredes:** Planning and Climate Change Unit | Ministry of Energy of Chile
- **Andrés Pereira:** CEPAL Consultant
- **Aaron Schubert:** Director| Coalition for Disaster Resilient Infraestructure
- **Juan Piedra:** Head of Planning for Disaster Risk Management | SENAPRED
- **Joan Romero:** Head of the Resilience and Risk Management Unit | Ministry of Energy of Chile
- **Camila Vivanco:** InvestChile
- **Amit Tripathi:** Power Sector Advisor | Coalition for Disaster Resilient Infrastructure
- **Jorge Moreno:** Inodú
- **Victor Garcia Tapia:** International Energy Agency
- **Eduardo Zamora:** Head of Electric Systems | Transelec

7. Appendix

7.1 Appendix A. Economy level justifications for Table 3 ratings

- **Australia:** APEC alignment is rated High because the economy assessment shows that Australia explicitly treats resilience as managing physical climate and transition risks and returning service reliably, with named planning and funding instruments. IEA alignment is rated High because the narrative links resilience to reliability, energy security, and the transition pathway through local planning and capacity mechanisms. CDRI alignment is rated High because hazards and infrastructure resilience are linked to broader social and economic impacts and public programs and funding. CIGRE alignment is rated High because the assessment shows that it includes operational planning and performance approaches such as Unserved Energy and grid oriented measures.

- **Brunei Darussalam:** APEC alignment is rated Medium because the economy assessment shows planning references that relate to continuity and preparedness, but provides fewer explicit operational resilience elements. IEA alignment is rated Medium because energy security and supply continuity are present, but the transition reliability framing is less supported by detailed standards or performance metrics in the text. CDRI alignment is rated Low/Medium because the economy assessment shows limited explicit multi hazard inclusive infrastructure and development framing. CIGRE alignment is rated Medium because the economy subsection provides limited explicit grid standards, recovery practices, or performance metrics. For the Medium ratings, the core traceability limitation is that the economy assessment shows mainly plan level, with fewer explicit codes, metrics, recovery protocols, or financing instruments.

- **Canada:** APEC alignment is rated High because the assessment shows links between climate hazards and continuity to local adaptation and institutional responsibilities. IEA alignment is rated High because resilience is framed through security, reliability, and transition and modernization context. CDRI alignment is rated High because climate hazard impacts on infrastructure are tied to economic and societal impacts and public adaptation strategies. CIGRE alignment is rated High because standards development and system performance monitoring are explicitly described.

- **Chile:** APEC alignment is rated Medium/High because it explicitly uses PSMA Energía and the National Energy Policy to frame resilience as climate risk integration, continuity, and recovery, but the breadth of explicit coverage varies by dimension. IEA alignment is rated High because resilience is framed around reliability and security while managing transition and renewable integration challenges under climate stress. CDRI alignment is rated Medium because the text links hazards and infrastructure planning clearly, but provides more limited explicit linkage to inclusive development elements compared to the full CDRI framing. CIGRE alignment is rated High because grid performance and service continuity evidence is explicit, including SAIDI and planning and coordination needs.

- **People's Republic of China:** APEC alignment is rated Medium/High because hazards and continuity and planning needs are explicit, while coverage of some broader dimensions varies in the assessed text. IEA alignment is rated High because energy security and reliability are integrated with transition scale up context. CDRI alignment is rated Medium/High because infrastructure resilience is discussed and linked to broader development context in parts of the narrative. CIGRE alignment is rated Medium/High because grid operational measures and reliability management and congestion and curtailment context are discussed.

- **Hong Kong, China:** APEC alignment is rated Medium because the economy assessment shows an focus on continuity of supply under hazards but largely through utility practice rather than broad cross sector framing. IEA alignment is rated Medium/High because reliability and security are explicit and supported by performance metrics and operational measures, with less emphasis on broader transition framing. CDRI alignment is rated Low/Medium because inclusive development framing is limited in the assessed text given mature access. CIGRE alignment is rated Medium/High because the text includes explicit SAIDI and SAIFI performance reporting and operational resilience measures.

- **Indonesia:** APEC alignment is rated Medium because the narrative links hazards and continuity and preparedness through policy and planning, but breadth varies across dimensions. IEA alignment is rated Medium/High because security of supply and diversification and transition planning are explicit, including fuel and market risk elements. CDRI alignment is rated Medium/High because development and access linkage is present alongside hazard exposure and, where stated, external financing context. CIGRE alignment is rated Medium because modernization measures are described but technical standards, restoration governance, and performance metrics are less consistently explicit in the economy text.

- **Japan:** APEC alignment is rated High because resilience is explicit in governance and disaster cooperation, with clear preparedness and recovery framing. IEA alignment is rated High because reliability and security of supply are tied to transition and system evolution context. CDRI alignment is rated Medium/High because multi hazard infrastructure framing is present but inclusive development linkage is less central in the subsection. CIGRE alignment is rated High because grid specific operational, planning, and restoration measures and coordination institutions are described.

- **Republic of Korea:** APEC alignment is rated Medium/High because resilience is linked to security and planning and institutional measures, with selective breadth across dimensions. IEA alignment is rated High because reliability and security and performance are strongly emphasized, including transition context. CDRI alignment is rated Medium because development and inclusion are less central in the narrative given mature access. CIGRE alignment is rated Medium/High because performance metrics such as very low SAIDI are explicitly used to demonstrate system outcomes and grid management.

- **Malaysia:** APEC alignment is rated Medium/High because hazards and continuity and planning are explicit, while coverage of some broader dimensions varies. IEA alignment is rated High because security, reliability, and transition roadmap framing is clear. CDRI alignment is rated Medium because development and inclusion framing is present but less explicit than in higher CDRI cases. CIGRE alignment is rated Medium/High because utility and operator measures are described, though detailed standards and recovery metrics are less prominent.

- **Mexico:** APEC alignment is rated Medium/High because the narrative includes major disturbance experience and resilience relevant responses, though broader dimension coverage varies. IEA alignment is rated High because reliability and security framing through system operation and coordination is explicit, with transition planning elements. CDRI alignment is rated Medium because development and equity framing is less central than reliability and security. CIGRE alignment is rated Medium/High because reliability performance and grid protection and operational control are referenced.

- **New Zealand:** APEC alignment is rated High because resilience is explicit through local disaster resilience and adaptation planning and dry year risk management. IEA alignment is rated High because security and reliability in a high renewable system is framed alongside transition planning. CDRI alignment is rated Medium/High because multi hazard and infrastructure adaptation is explicit and connected to public strategy outcomes. CIGRE alignment is rated High because grid operation and planning and restoration governance through Transpower are described with strong specificity.

- **Papua New Guinea:** APEC alignment is rated Medium/High because the economy text links hazards, recovery needs, and service continuity directly to resilience in an access constrained context. IEA alignment is rated Medium because fuel import dependence and basic reliability challenges are explicit, with less detail on transition related resilience. CDRI alignment is rated Medium/High because the narrative explicitly links resilience to development and access, rural vulnerability, and coordination with development partners. CIGRE alignment is rated Low/Medium because utility challenges and mini grid context are described but the text contains fewer explicit technical standards, restoration protocols, or performance metrics.

- **Peru:** APEC alignment is rated Medium/High because resilience is linked to climate hazards and planning and service continuity through framework instruments. IEA alignment is rated Medium/High because reliability and security framing is explicit and transition context appears in planning references. CDRI alignment is rated Medium/High because development and access and service quality differentiation between urban and rural systems is explicitly addressed. CIGRE alignment is rated Medium because standards and quality of service regulation are described, while broader recovery governance and resilience performance metrics beyond standard reliability indicators are less detailed.

- **The Republic of the Philippines:** APEC alignment is rated High because resilience is operationalized through explicit sector requirements and tools and frequent hazard recovery experience. IEA alignment is rated High because reliability and security under hazard stress is explicit and tied to system strengthening. CDRI alignment is rated High because multi hazard infrastructure recovery and inclusive service continuity issues through electric cooperatives are central in the narrative. CIGRE alignment is rated High because grid restoration and operational resilience measures and performance issues are explicitly discussed.

- **The Russian Federation:** APEC alignment is rated Medium because resilience is often framed through energy security and stability, with adaptation referenced but less explicitly organized around the full APEC definition elements. IEA alignment is rated Medium/High because energy security doctrines and long term strategy framing align with IEA's security and reliability lens. CDRI alignment is rated Low/Medium because inclusive development and multi hazard infrastructure framing is less explicit than security doctrine framing in the assessed text. CIGRE alignment is rated Medium because operational and emergency control practices are described, but comparable technical standards and resilience performance metrics are less consistently presented.

- **Singapore:** APEC alignment is rated High because resilience is explicitly defined and tied to preparedness and recovery and system flexibility. IEA alignment is rated Medium/High because security and reliability framing is explicit, while transition context reflects a constrained system with import dependence. CDRI alignment is rated Low/Medium because inclusive development framing is limited in the assessed text given mature access. CIGRE alignment is rated High because the text emphasizes operational practices, digital monitoring, and system management consistent with grid resilience framing.

- **Chinese Taipei:** APEC alignment is rated Medium/High because resilience is linked to hazards and continuity and recovery through planning and institutional measures, but explicit coverage is less uniform across all dimensions. IEA alignment is rated Medium/High because the assessment shows security and reliability framing and transition context with moderate operational specificity. CDRI alignment is rated Medium because development and inclusion are less central in a mature access context. CIGRE alignment is rated Medium/High because grid focused measures are discussed, though detailed standards and recovery performance indicators are less prominent than in the highest alignment cases.

- **Thailand:** APEC alignment is rated Medium because resilience is linked to hazards and recovery within planning narratives, but explicit operationalization and breadth varies. IEA alignment is rated Medium because transition and efficiency are present, but explicit resilience governance and standards are less detailed in the economy narrative. CDRI alignment is rated Medium/High because infrastructure and sustainable development framing is present through long term strategies. CIGRE alignment is rated Medium because SAIDI and SAIFI are explicitly reported, while broader operational and recovery governance detail is less extensive.

- **United States:** APEC alignment is rated High because resilience is framed as a core policy objective linked to hazards and recovery and critical infrastructure protection. IEA alignment is rated High because reliability and security standards and investment mechanisms are explicit and connected to system modernization. CDRI alignment is rated Medium/High because infrastructure resilience and public welfare framing is present, while inclusive development framing varies by program type in the narrative. CIGRE alignment is rated High because NERC reliability standards, planning and operational measures, and grid investment programs are explicitly discussed.

- **Viet Nam:** APEC alignment is rated Medium/High because the economy text explicitly states that adaptation and resilience need to be incorporated into planning and infrastructure development for continuity under stress. IEA alignment is rated Medium/High because energy security resolutions and planning instruments are referenced alongside transition pressures and reliability concerns. CDRI alignment is rated Medium/High because climate risk, infrastructure development, and resilience needs are linked in a multi hazard development context in the narrative. CIGRE alignment is rated Medium because SAIDI and SAIFI are reported and used for performance description, while detailed recovery governance and technical standards are less extensive than in the highest alignment cases.

Bibliography

[1] Oyewunmi, T. (2021). Resilience, reliability and gas to power systems in the USA: An energy policy outlook in the era of decarbonization. The Journal of World Energy Law & Business, 14(4), 257–276. https://doi.org/10.1093/jwelb/jwab022

[2] APEC Energy Working Group. (2020). Energy Resiliency: APEC Energy Working Group 59 Final Report (EWG59/2020/023). Asia-Pacific Economic Cooperation. https://mddb.apec.org/Documents/2020/EWG/EWG59/20_ewg59_023.pdf

[3] International Energy Agency (IEA). (2025). Climate Resilience Policy Indicator. https://www.iea.org/reports/climate-resilience-policy-indicator/climate-resilience-policy-indicator#abstract

[4] International Energy Agency (IEA). (2025). Climate Resilience for Energy Security in Southeast Asia. https://iea.blob.core.windows.net/assets/4c5449ca-edde-4c54-8b86-61616c7c8c64/ClimateResilienceforEnergySecurityinSoutheastAsia.pdf

[5] Coalition for Disaster Resilient Infrastructure (CDRI). (n.d.). DRI Lexicon Introduction. https://lexicon.cdri.world/front/images/DRI-Lexicon-Introduction.pdf

[6] European Commission. (2025). Flexibility for Resilience (MJ-07-22-296-ENN). https://smart-networks-energy-transition.ec.europa.eu/sites/default/files/2025-12/flexibility%20for%20resilience-MJ0722296ENN.pdf

[7] Coalition for Disaster Resilient Infrastructure (CDRI). (2022). G20 Brazil Compendium on Disaster Resilient Infrastructure. https://cdri.world/upload/pages/G20_Brazil_Compendium.pdf

[8] United Nations Office for Disaster Risk Reduction (UNDRR). (2019). *Enhancing infrastructure resilience*. https://www.undrr.org/resilient-infrastructure/enhance-infrastructure-resilience

[9] World Bank. (2019). *Strengthening new infrastructure assets: A cost–benefit analysis*. https://documents1.worldbank.org/curated/en/962751560793977276/pdf/Strengthening-New-Infrastructure-Assets-A-Cost-Benefit-Analysis.pdf

[10] Building Resilience Coalition. (2021). *The costs of resiliency*. https://buildingresiliencecoalition.org/the-costs-of-resiliency/

[11] New Development Bank (NDB). (2024). *Building climate resilience in*

infrastructure projects: A brief for investors. https://www.ndb.int/wp-content/uploads/2024/03/Building-Climate-Resilience-in-Infrastructure-Projects-A-Brief-for-Investors.pdf

[12] Australian Energy Market Operator. (2025). Annual Report FY25. https://www.aemo.com.au/-/media/files/about_aemo/annual-report/2025/annual-report-fy25.pdf?rev=d7a3a989b46b4e038cff0d1edde0a658&sc_lang=en

[13] Australian Energy Market Operator. (2025). Victorian Annual Planning Report 2025. https://www.aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/vapr/2025/2025-victorian-annual-planning-report.pdf?rev=170d75d5022a4fa8842c0010e3cacc0e&sc_lang=enInternational Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), Hydrogen Certification 101 https://www.iphe.net/hydrogen-certification-101-oct-24

[14] VicGrid. (2025). Planning the energy grid. https://www.vicgrid.com.au/transmission-planning/planning-the-energy-gridInternational Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), Hydrogen Certification 101 https://www.iphe.net/hydrogen-certification-101-oct-24

[15] Victorian Government. (n.d.). Victorian Transmission Investment Framework. https://engage.vic.gov.au/victorian-transmission-investment-framework

[16] Australian Accounting Standards Board. (2025). AASB S2 Climate-related Disclosures. https://standards.aasb.gov.au/sites/default/files/2025-01/AASBS2_09-24.pdf

[17] Australian Energy Regulator. (n.d.). Guidance on efficient management system strength framework. https://www.aer.gov.au/industry/registers/resources/reviews/guidance-efficient-management-system-strength-framework

[18] Australian Energy Market Operator. (2025). FY25 Annual Results Presentation. https://www.aemo.com.au/-/media/files/about_aemo/annual-report/2025/fy25-annual-results-presentation.pdf?rev=cf98612be47e45818132ee3a09ec3719&sc_lang=en

[19] Australian Energy Market Operator. (2025). 2025 General Power System Risk Review. https://www.aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2024/2025-general-power-system-risk-review/2025-gpsrr.pdf?rev=dc6a972e71544bd3893299a4aaacf867&sc_lang=en

[20] Australian Energy Regulator. (2025). State of the Energy Market 2025 – Full

Report. https://www.aer.gov.au/documents/state-energy-market-2025-full-report

[21] Australian Energy Market Operator. (n.d.). 2026 Integrated System Plan (ISP). https://www.aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2026-integrated-system-plan-isp

[22] Australian Energy Market Operator. (2025). 2025 Inputs, Assumptions and Scenarios Report. https://www.aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2024/2025-iasr-scenarios/final-docs/2025-inputs-assumptions-and-scenarios-report.pdf?rev=63268acd3f044adb9f5f3a32b6880c27&sc_lang=en

[23] Australian Government, National Emergency Management Agency. (2025). Disaster Ready Fund. https://www.nema.gov.au/our-work/key-programs/disaster-ready-fund#RoundFour

[24] PV Tech (2023). Australia faces grid reliability issues without urgent investment. https://www.pv-tech.org/australia-faces-grid-reliability-issues-without-urgent-investment-aemo/#:~:text=Or%20continue%20reading%20this%20article,and%20Queensland%20in%202028%2D29

[25] Australian Renewable Energy Agency, Australian renewable energy agency anual report 2023-24, accessed: 2025-04-24 (2024). URL https://www.transparency.gov.au/publications/climate-change-energy-the-environment-and-water/australian-renewable-energy-agency/australian-renewable-energy-agency-annual-report-2023-24

[26] Infrastructure Victoria, Victoria's draft 30-year infrastructure strategy 2025-2055, accessed: 2025-04-25 (2025). URL https://www.infrastructurevictoria.com.au/resources/draft-30-year-strategy

[27] EnergyCo NSW. (n.d.). Waratah Super Battery Project. https://www.energyco.nsw.gov.au/our-projects/waratah-super-battery-project

[28] Government of Brunei Darussalam. (2020). Brunei Darussalam national climate change policy. PreventionWeb. https://www.preventionweb.net/publication/brunei-darussalam-national-climate-change-policy

[29] Adedeji, A. R., Zaini, F., Mathew, S., Dagar, L., Petra, M. I., & De Silva, L. C. (2020). Sustainable energy towards air pollution and climate change mitigation. Journal of Environmental Management, 260, 109978. https://doi.org/10.1016/j.jenvman.2019.109978

[30] Center for Excellence in Disaster Management & Humanitarian Assistance. (2022). Brunei disaster management reference handbook 2022. PreventionWeb. https://www.preventionweb.net/publication/brunei-disaster-management-reference-handbook-2022

[31]Government of Brunei Darussalam, Ministry of Finance and Economy, Department of Economic Planning and Statistics. (2024). *Twelfth National Development Plan (RKN12) 2024–2029: Strengthening socioeconomic development to ensure prosperity and harmony of the country*. https://deps-1d68840ecf-hehjcxeeeybfdabn.a03.azurefd.net/wp-content/uploads/2025/11/RKN12-English.pdf

[32] Borneo Bulletin. (2025). *BND 480 million for development*. https://borneobulletin.com.bn/bnd480-million-for-development/

[33] Government of Brunei Darussalam. (2025). Brunei Darussalam's National Adaptation Plan for Climate Change. https://unfccc.int/sites/default/files/resource/Brunei%20Darussalam%27s%20National%20Adaptation%20Plan.pdf

[34] World Bank Group. (2020). *Doing Business 2020: Brunei Darussalam – Getting electricity*. https://archive.doingbusiness.org/content/dam/doingBusiness/country/b/brunei/BRN.pdf

[35] Government of Brunei Darussalam. (2015, November 30). Brunei Darussalam's intended nationally determined contribution (INDC). UNFCCC. https://www4.unfccc.int/sites/submissions/INDC/Published%20Documents/Brunei/1/Brunei%20Darussalam%20INDC_FINAL_30%20November%202015.pdf

[36] Energy Department, Prime Minister's Office. (2014). Brunei Darussalam energy white paper. https://policy.asiapacificenergy.org/sites/default/files/Energy%20White%20Paper%202014%281%29.pdf

[37] Natural Resources Canada. (2025). Energy fact book 2025–2026. Government of Canada. https://publications.gc.ca/collections/collection_2025/rncan-nrcan/M136-1-2025-eng.pdf

[38] Organisation for Economic Co-operation and Development. (2025). OECD economic surveys: Canada 2025. OECD Publishing. https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/05/oecd-economic-surveys-canada-2025_ee18a269/28f9e02c-en.pdf

[39] Electricity Canada. (2025). Standards for our energy future 2025.

https://www.electricity.ca/files/Standards-for-our-Energy-Future-2025.pdf

[40] Statistics Canada. (2025, September 24). Table 17-10-0009-01: Population estimates, quarterly. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000901

[41] Hydro One Limited. (2025, April 28). 2025 management information circular. https://www.hydroone.com/abouthydroone/CorporateInformation/Documents/AGM-2025-MIC.pdf

[42] Office of the Auditor General of British Columbia. (2019). Rate-regulated accounting at BC Hydro. https://www.oag.bc.ca/app/uploads/sites/963/2024/07/OAGBC-2019-02-01-OAGBC_RRA_RPT.pdf

[43] Electricity Canada, Navigating canada's energy transition, accessed: 2025-05-27 (2024). URL https://www.electricity.ca/knowledge-centre/journal/navigating-canadas-energy-transition

[44] State Grid Corporation of China, China to invest $800 billion in power grid over six years, accessed: 2025-05-25 (2023). URL http://www.xinhuanet.com/english/2023-article-url

[45] Ilustre Municipalidad de Río Claro, *Estrategia Energética Local de la Comuna de Río Claro*, accessed: 2025-11-23 (2021). https://comunaenergetica.cl/wp-content/uploads/2021/07/EEL-Rio-Claro.pdf.

[46] InvestChile, *Electricity generation in Chile 2024: 68% originated from renewables*, accessed: 2025-11-23 (2025). https://blog.investchile.gob.cl/electricity-generation-chile-2024

[47] Biblioteca del Congreso Nacional de Chile, *Ley 21.455: Ley Marco de Cambio Climático*, accessed: 2025-11-23 (2022). https://www.bcn.cl/leychile/navegar?idNorma=1177286 Biblioteca Congreso Chile+1

[48] Ministerio de Energía. (2022). *Transición Energética de Chile Política Energética Nacional (actualización 2022)*. Gobierno de Chile. ttps://energia.gob.cl/sites/default/files/documentos/pen_2050_-_actualizado_marzo_2022_0.pdf

[49] Ministerio de Energía, *Cambio Climático – Energía*, accessed: 2025-11-23 (2025). URL https://energia.gob.cl/cambioclimatico Ministerio de Energía

[50] Centro de Energía de la Universidad de Chile & GIZ, *Análisis de infraestructura resiliente a la crisis climática para el sector energético*, accessed: 2025-11-23 (2022). https://energia.gob.cl/sites/default/files/documentos/analisis_de_infraestruct

ura_resiliente_a_la_crisis_climatica_para_el_sector_energetico.pdf%20Ministerio%20de%20Energía+1.

[51] Centro de Ciencia del Clima y la Resiliencia (CR2), *Informe a la Nación: La megasequía en Chile*, accessed: 2025-11-23 (2015). https://www.cr2.cl/megasequia/ CR2+1

[52] El País, *Alerta por el calor extremo en Chile: cuáles son las regiones afectadas y cuándo bajarán las temperaturas*, accessed: 2025-11-23 (2025). URL https://elpais.com/chile/2025-03-18/alerta-por-el-calor-extremo-en-chile-cuales-son-las-regiones-afectadas-y-cuando-bajaran-las-temperaturas.html El País

[53] Empresas Eléctricas A.G., *Memoria Anual 2023*, accessed: 2025-11-23 (2024). URL https://www.electricas.cl/wp-content/uploads/2024/05/Memoria-EEAG-2023.pdf

[54] Observatorio de la Transición Energética (ODTE), *SAIDI Nacional según tipo (2012–2023)*, accessed: 2025-11-23. URL https://odte.cl/saidi-nacional-segun-tipo-2012-2023

[55] Ministerio de Energía. (2024). Plan de adaptación y mitigación al cambio climático del sector energía: Informe final. Gobierno de Chile. https://energia.gob.cl/sites/default/files/documentos/202408_proyecto_id_584105-5-lq24_plan_de_adaptacion_y_mitigacion_al_cambio_climatico_sector_energia.pdf

[56] Ministerio de Energía. (2025). Long-term energy planning 2023–2027 (PELP): Definitive report. Gobierno de Chile. https://energia.gob.cl/sites/default/files/documentos/definitive_report_pelp_2023-2027.pdf

[57] Biblioteca del Congreso Nacional de Chile, *Ley 18.410: Crea la Superintendencia de Electricidad y Combustibles*, accessed: 2025-11-23 (1985). URL https://www.bcn.cl/leychile/navegar?idNorma=29819 Biblioteca Congreso Chile+1

[58] Comisión Nacional de Energía (CNE), *Norma Técnica de Seguridad y Calidad de Servicio (NTSyCS), enero 2025*, accessed: 2025-11-23 (2025). URL https://www.cne.cl/wp-content/uploads/2025/01/NTSyCS-Ene-2025.pdf CNE

[59] Coordinador Eléctrico Nacional, *Nuestro enfoque – Misión y visión*, accessed: 2025-11-23 (2017). URL https://www.coordinador.cl/coordinador/nuestro-enfoque/ coordinador.cl

[60] Ministerio de Energía, *SEC multa con casi $4 mil millones a Enel por*

problemas en medio de lluvias del 7 de mayo, accessed: 2025-11-23 (2024). URL https://energia.gob.cl/noticias/nacional/sec-multa-con-casi-4-mil-millones-enel-por-problemas-en-medio-de-lluvias-del-7-de-mayo Sec.cl+2La Tercera+2

[61] El País, *De las fallas del sistema a los responsables: claves del mega apagón que dejó Chile a oscuras*, accessed: 2025-11-23 (2025). URL https://elpais.com/chile/2025-02-27/de-las-fallas-del-sistema-a-los-responsables-claves-del-mega-apagon-que-dejo-chile-a-oscuras.html El País+1

[62] Coordinador Eléctrico Nacional. (2025). *Propuesta Final De Expansión De La Transmisión Proceso De Planificación De La Transmisión 2025. https://www.coordinador.cl/wp-content/uploads/2025/01/Informe-Final-PET2025.pdf*

[63] Gobierno de Chile. (2022). *Ley marco de cambio climático* (Ley N.º 21.455). Biblioteca del Congreso Nacional de Chile. https://www.bcn.cl/leychile/navegar?idNorma=1177286

[64] Ministerio del Medio Ambiente. (2021). *Estrategia climática de largo plazo de Chile*. Gobierno de Chile. https://cambioclimatico.mma.gob.cl/wp-content/uploads/2021/11/ECLP-LIVIANO.pdf

[65] Ministerio de Energía, *Plan de Adaptación al Cambio Climático para el Sector Energía 2018–2023*, accessed: 2025-11-23 (2018). URL https://energia.gob.cl/sites/default/files/documentos/201812_plan_adaptacion_energia_2018-2023_foliado_0.pdf Ministerio de Energía

[66] World Bank. (2019). Stronger power: Improving power sector resilience to natural hazards. https://documents1.worldbank.org/curated/en/200771560790885170/pdf/Stronger-Power-Improving-Power-Sector-Resilience-to-Natural-Hazards.pdf

[67] International Energy Agency. (2023). Building a unified national power market system in China: Pathways for spot power markets. https://www.iea.org/reports/building-a-unified-national-power-market-system-in-china

[68] International Energy Agency. (2018). Power sector reform in China: An international perspective. https://www.iea.org/reports/power-sector-reform-in-china

[69] State Grid Corporation of China, China to invest $800 billion in power grid over six years, accessed: 2025-05-25 (2023). URL http://www.xinhuanet.com/english/2023-article-url

[70] China Daily. (2024). China's state grid boosts investment in ultra-high-

voltage transmission and smart grid technologies. https://global.chinadaily.com.cn/a/202408/28/WS66ce889ea31060630b9255d6.html

[71] International Energy Agency, Renewable energy market update– outlook for 2023 and 2024, accessed: 2025-05-25 (2023). URL https://www.iea.org/reports/renewable-energy-market-update-2023

[72] National Development and Reform Commission, Outline of the 14th five-year plan for national economic and social development, accessed: 2025-05-25 (2021). URL https://www.ndrc.gov.cn/fggz/fzzlgh/gjjzxgh/202103/t20210313_1265575.html

[73] Dzvene, A. R., Zhou, L., Slayi, M., & Dirwai, T. L. (2025). A scoping review on challenges and measures for climate change in arid and semi-arid agri-food systems. Discover Sustainability, 6, Article 151. https://doi.org/10.1007/s43621-025-00945-z

[74] Li, X., & Su, F. (2025). Geography and rural-urban divide: A study on public perception towards climate change, carbon neutrality, and green energy policies in China. Sustainable Futures, 10, 101394. https://doi.org/10.1016/j.sftr.2025.101394

[75] Hu, X., Zhang, W., Zhang, S., Hao, Y., & Cong, J. (2025). The impacts of the global energy transition on China’s energy security in the long-term: Heterogeneous evidence from the supply and consumption sides. Renewable Energy, 255, 123784. https://doi.org/10.1016/j.renene.2025.123784

[76] Ministry of Ecology and Environment of the People’s Republic of China. (2022). China’s policies and actions for addressing climate change. https://english.mee.gov.cn/Resources/Reports/reports/202211/P020221110605466439270.pdf

[77] 17 Departments of the PRC. (2022). *National Climate Change Adaptation Strategy 2035*. https://www.mee.gov.cn/xxgk2018/xxgk/xxgk03/202206/W020220613451903038545.pdf

[78] China Government. (2022). *China aims to build a climate-resilient society by 2035*. https://english.www.gov.cn/statecouncil/ministries/202206/14/content_WS62a8342cc6d02e533532c23a.html

[79] H. Chen, X. Chen, J. Niu, M. Xiang, W. He, S. Küfeoğlu, Estimating the marginal cost of reducing power outage durations in china: A parametric distance function approach, Energy Policy 155 (2021) 112366.

https://doi.org/10.1016/j.enpol.2021.112366

[80] Government of the Hong Kong Special Administrative Region, Environment and Ecology Bureau (Environment Branch)URL https://www.eeb.gov.hk/en/energy/energy.html

[81] Research Office, Legislative Council Secretariat, Implications of Enhanced Competition in Electricity Generation in Selected Places, accessed: 2025-11-25 (2024). URL https://app7.legco.gov.hk/rpdb/en/uploads/2024/RT/RT01_2024_20240115_en.pdf

[82] HK Electric, Sustainability Report 2023, accessed: 2025-11-25 (2023). URL https://www.hkelectric.com/documents/en/CorporateSocialResponsibility/CorporateSocialResponsibility_CDD/Documents/SR2023E_SASBCI.pdf

[83] Government of the Hong Kong Special Administrative Region, Climate Action Plan 2050 of Hong Kong, accessed: 2025-11-25 (2021). URL https://www.gov.hk/en/residents/environment/global/climate.htm

[84] Liu, Yifan, CLP Power launches AI-driven system to bolster resilience against extreme weather, accessed: 2025-11-25 (2025). URL https://www.chinadailyhk.com/hk/article/604292?utm

[85]The Government of the Hong Kong Special Administrative Region. (2025). LegCo Panel on Environmental Affairs visits innovative technology projects of CLP. GovHK. https://www.info.gov.hk/gia/general/202506/03/P2025060300537.htm

[86] Hong Kong Special Administrative Region Government. (2021). *Hong Kong's climate action plan 2050*. Environment Bureau. https://www.eeb.gov.hk/sites/default/files/pdf/cap_2050_en.pdf

[87] Government of the Hong Kong Special Administrative Region. (2017). *Scheme of control agreement between the Government of the Hong Kong Special Administrative Region and CLP Power Hong Kong Limited and Castle Peak Power Company Limited* https://www.eeb.gov.hk/sites/default/files/en/node66/SCA_of_CLP_Eng_txt.pdf

[88] Hong Kong Special Administrative Region Government, Environment and Ecology Bureau. (2023). *2024–28 development plans and 2024 electricity tariff review of CLP Power Hong Kong Limited and Hongkong Electric Company Limited*. https://www.info.gov.hk/gia/general/202311/28/P2023112800659.htm

[89]CLP Power Hong Kong Limited. (2026). CLP Power adopts multi-pronged approach to accelerate implementation of measures outlined in Review Results

Report to further enhance resilience of power supply system. CLP Power Hong Kong Limited. https://www.clp.com.hk/content/dam/clp-group/channels/media/document/2026/20260102_EN.pdf

[90] Government of Indonesia. (2009). Law of the Republic of Indonesia No. 30 Year 2009 on electricity. Government of Indonesia. https://conferenceproceedings.ump.ac.id/pssh/article/download/1013/1100/1355 repit.files.wordpress.com+2policy.asiapacificenergy.org+2

[91] International Energy Agency. (2015). Indonesia 2015: Energy policies beyond IEA countries. International Energy Agency. https://iea.blob.core.windows.net/assets/7a823189-4570-4161-916e-cd65a8052f05/Indonesia_IDR.pdf

[92] Government of Indonesia. (2014). *Government Regulation of the Republic of Indonesia No. 79 Year 2014 on National Energy Policy (KEN)*. Government of Indonesia. https://policy.asiapacificenergy.org/sites/default/files/Government%20Regulation%20No.%2079%3A2014%20of%202014%20%28EN%29.pdf policy.asiapacificenergy.org

[93] Government of Indonesia. (2017). *Presidential Regulation No. 22 Year 2017 on National Energy General Plan (RUEN)*. Government of Indonesia. https://www.iea.org/policies/2456-general-plan-for-national-energy-presidential-regulation-no22-year-2017 IEA

[94]Ministry of Energy and Mineral Resources of the Republic of Indonesia. (2022). SAIDI and SAIFI show service quality is getting better, says Electricity Director General [Press release]. https://www.esdm.go.id/en/media-center/news-archives/capaian-saidi-dan-saifi-tunjukkan-mutu-layanan-listrik-kian-optimal-

[95] Government of Indonesia. (2022). *Enhanced nationally determined contribution (ENDC) of Indonesia*. United Nations Framework Convention on Climate Change (UNFCCC). https://unfccc.int/sites/default/files/NDC/2022-09/23.09.2022_Enhanced%20NDC%20Indonesia.pdf

[96] Setyawati, D., & Setiawan, D. (2024). *Indonesia's expansion of clean power can spur growth and equality*. Ember Climate. https://ember-energy.org/latest-insights/indonesias-expansion-of-clean-power-can-spur-growth-and-equality/ Ember Energy+2Fastmarkets+2

[97] Government of Indonesia. (2025). *National Adaptation Plan (NAP): 2026–2030, on the pathway toward 2035*. United Nations Framework Convention on Climate Change (UNFCCC).

https://unfccc.int/sites/default/files/resource/NAP_Indonesia__2025__.pdf UNFCCC+2UNFCCC+2

[98] Government of Indonesia. (2007). *Law of the Republic of Indonesia No. 24 Year 2007 concerning Disaster Management*. Government of Indonesia. https://www.preventionweb.net/english/professional/policies/v.php?id=3105

[99] International Energy Agency, Climate resilience for energy security in south east asia, https://www.iea.org/reports/climate-resilience-for-energy-security-in-southeast-asia, accessed: 2025-05-22 (2024).

[100] OECD, Adapting infrastructure to changing climatic conditions: The case of indonesia, https://doi.org/10.1787/75547f67-en accessed: 2025-05-22 (2024).

[101] World Bank. (2023). *Indonesia – Electricity Network Transformation (I-ENET) Program-for-Results (P180992): Program documents and environmental and social systems assessment (ESSA)*. World Bank. https://documents1.worldbank.org/curated/en/099051624055016681/pdf/P18099214f46e405186ed19449f8da852c.pdf

[102] Reuters. (2025). *Indonesia plans to boost renewable usage in new electricity supply plan*. https://www.reuters.com/world/asia-pacific/indonesia-plans-boost-renewable-usage-new-electricity-supply-plan-2025-02-11/ Reuters+1

[103] Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry. (2021). *The 6th strategic energy plan* (Cabinet decision, October 2021). https://www.enecho.meti.go.jp/category/others/basic_plan/pdf/strategic_energy_plan.pdf enecho.meti.go.jp+1

[104] International Energy Agency. (2022). *Japan electricity security policy: Analysis*. https://www.iea.org/articles/japan-electricity-security-policy

[105] Government of Japan. (2002). *Basic Act on Energy Policy (Act No. 71 of 2002)*. Japanese Law Translation. https://www.japaneselawtranslation.go.jp/en/laws/view/3818/en Reuters

[106] Reuters. (2024). *Japan targets 40–50% power supply from renewable energy by 2040*. https://www.reuters.com/sustainability/climate-energy/japan-targets-40-50-power-supply-renewable-energy-by-2040-2024-12-17/ Reuters+1

[107] Cabinet Office, Government of Japan. (2018). *Fundamental plan for national resilience*.

https://www.cas.go.jp/jp/seisaku/kokudo_kyoujinka/en/fundamental_plan.pdf

[108] Cabinet Office, Government of Japan. (2021). *Disaster management in Japan: White paper 2021*. https://www.bousai.go.jp/en/documentation/white_paper/pdf/2021/R3_hakusho_english.pdf

[109] Cabinet Office, Government of Japan. (2018–2024). *National resilience (Kokudo Kyoujinka) policy documents*. https://www.cas.go.jp/jp/seisaku/kokudo_kyoujinka/en/fundamental_plan.pdf

[110] Government of Japan. (2016). *Basic Act on Disaster Management*. Japanese Law Translation. https://www.japaneselawtranslation.go.jp/en/laws/view/3322/en

[111] Government of Japan. (2021). *The long-term strategy under the Paris Agreement*. United Nations Framework Convention on Climate Change (UNFCCC). https://unfccc.int/sites/default/files/resource/Japan_LTS2021.pdf UNFCCC+1

[112] Ministry of the Environment, Government of Japan. (2021). *National climate change adaptation plan*. https://www.env.go.jp/content/000081210.pdf

[113] Japan Electric Power Information Center. (2025). *The electric power industry in Japan* (2024–2025 ed.). https://www.jepic.or.jp/en/data/pdf/epijJepic2025.pdf

[114] Government of Japan, Ministry of Economy, Trade and Industry. (2020). *Act for establishing energy supply resilience (partial revision of the Electricity Business Act and other acts)*. Japan Electric Power Information Center. https://www.jepic.or.jp/en/data/pdf/epijJepic2024.pdf

[115] World Bank. (2025). *Strengthening Japan's power system resilience*. World Bank. https://thedocs.worldbank.org/en/doc/eb847365035f52d6e3b2a8ef00aae974-0450022025/original/Strengthening-Japans-Power-System-Resilience.pdf The World Bank

[116] Government of Japan, Cabinet Secretariat. (2022). *White paper on disaster management in Japan 2022*. https://www.bousai.go.jp/en/documentation/white_paper/2022.html

[117] Government of Japan, Ministry of Finance. (2023). *Japanese public finance fact sheet 2023*.

https://www.mof.go.jp/english/policy/budget/budget/fy2023/02.pdf

[118] Government of Japan, Ministry of Economy, Trade and Industry. (2025). *Strategic energy plan*. https://www.enecho.meti.go.jp/category/others/basic_plan/pdf/2025_strategic_energy_plan.pdf

[119] Organization for Cross-regional Coordination of Transmission Operators. (2024). *Report on the quality of electricity supply: Data for fiscal year 2022*. https://www.occto.or.jp/en/assets/information_disclosure/report_on_the_quality/files/2022_qualityofelectricity_240131.pdf

[120] Korea Energy Economics Institute. (2025, November). Monthly energy statistics (2025.11) ReportReportReport. https://kesis.keei.re.kr/board.es?mid=a20301010000&bid=0046&act=view&list_no=2470

[121] SHIN & KIM LLC. (2025, July 11). New Korean government's energy policy direction NewsletterNewsletterNewsletter. https://shinkim.com/eng/media/newsletter/2897

[122] Asia Investor Group on Climate Change. (2025, June). South Korea – State of investor climate transition 2025 ReportReportReport. https://aigcc.net/wp-content/uploads/2025/07/Korea_Climate-Transition-Report-market-summary-English.pdf

[123] Kim, D., Kwag, S., Jung, R., & Eem, S. (2025, May 22–23). Investigating natural disaster cases due to climate change and potential risks to nuclear power plants ConferencepaperConference paperConferencepaper. Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea. https://www.kns.org/files/pre_paper/53/25S-257-%EA%B9%80%EB%8F%99%EC%B0%BD.pdf

[124] Lee, E., Böer, B., Surendra, L., Chun, J. A., & Taniguchi, M. (Eds.). (2024). The water, energy, and food security nexus in Asia and the Pacific: East and Southeast Asia (1st ed.). Springer Cham. https://doi.org/10.1007/978-3-031-12495-2

[125] Korea Energy Economics Institute. (2024). 2025 Korea energy outlook (H2 2024 ed.; Vol. 26, No. 2) ReportReportReport. https://kesis.keei.re.kr/pdfOpen.es?bid=0053&list_no=1061&seq=4

[126] International Finance Corporation, Korea green resilient and innovative develop ment (k-grid), accessed: 2025-05-11 (2024). URL https://www.ifc.org/en/what-we-do/sector-expertise/blended-finance/climate/korea-green-resilient-and-innovative-development-program

Xxx

[127] G.-j. Kim, Ulsan city, ’hydrogen city development project’ competition selection: 14.7 billion won in national funds secured, accessed: 2025-05-15 (2024). URL https://www.yna.co.kr/view/AKR20240919158400057

[128] Ministry of Economy (Malaysia). (2023, August 29). National Energy Transition Roadmap (NETR). https://ekonomi.gov.my/sites/default/files/2023-08/National%20Energy%20Transition%20Roadmap.pdf

[129] Kumar, M. (2021, January). Electricity supply industry reform and design of competitive electricity market in Malaysia. Oxford Institute for Energy Studies. https://www.oxfordenergy.org/wpcms/wp-content/uploads/2021/01/Electricity-Supply-Industry-Reform-and-Design-of-Competitive-Electricity-Market-in-Malaysia.pdf

[130] National Hydraulic Research Institute of Malaysia (NAHRIM). (2021). Malaysia Adaptation Index (MAIN): Technical document. https://main.nahrim.gov.my/images/pdf/MAIN_TECHNICAL_DOCUMENT.pdf

[131] Huda, M. S., Seah, S., & Qiu, J. (2023, December 12). Accelerating the ASEAN Power Grid 2.0: Lessons from the Lao PDR–Thailand–Malaysia–Singapore Power Integration Project (LTMS-PIP) (Policy report). ISEAS – Yusof Ishak Institute. https://www.iseas.edu.sg/wp-content/uploads/2023/11/2023-LTMS-PIP-Policy-Report-FA-V2-Online.pdf

[132] Government of Malaysia, Economic Planning Unit, Prime Minister’s Department. (2021). *Twelfth Malaysia plan, 2021–2025: A prosperous, inclusive, sustainable Malaysia*. https://pulse.icdm.com.my/wp-content/uploads/2021/09/Twelfth-Plan-Document_compressed-1.pdf

[133] Ministry of Finance Malaysia. (2022). *Pre-budget statement 2023*. https://phl.hasil.gov.my/pdf/pdfam/MoF_PreBudget_Statement_2023.pdf

[134] Ministry of Finance Malaysia. (2025). *Economic outlook 2026*. https://belanjawan.mof.gov.my/pdf/belanjawan2026/economy/economic-2026.pdf

[135] Energy Commission Malaysia. (2022). *Malaysia energy statistics handbook 2022 (updated)*. https://www.st.gov.my/contents/files/download/116/Malaysia%20Energy%20Statistics%20Handbook%202022%20%28Updated%29.pdf

[136] Energy Commission Malaysia. (2023). *Malaysia energy statistics handbook 2023*. Suruhanjaya Tenaga.https://www.st.gov.my/contents/files/download/99/Malaysia_Energy_Statistics_Handbook_2023.pdf

[137] Proyectos México, Electricidad – Ciclo de Inversión de la Cartera de Infraestructura Mexicana, accessed: 2025-11-23 (s/f). URL https://www.proyectosmexico.gob.mx/en/how-mexican-infrastructure/investment-cycle/electricity/

[138] Secretaría de Energía (SENER), Programa de Desarrollo del Sistema Eléctrico Nacional (PRODESEN) 2023–2037. Capítulo 1. Marco de referencia, accessed: 2025-11-23 (2023). https://base.energia.gob.mx/PRODESEN2023/Capitulo1.pdf

[139] Secretaría de Energía (SENER), *Misión, visión y objetivos del sector energía*, accessed: 2025-11-23 (2024). URL https://transparencia.energia.gob.mx/web_transparencia/3_APERTURA_GUBERNAMENTAL/3_1_INFORMACION_SOCIALMENTE_UTIL/3_1_1_1_mision_vision_objetivos.pdf

[140] Secretaría de Energía (SENER), *Programa de Desarrollo del Sistema Eléctrico Nacional (PRODESEN)*, accessed: 2025-11-23 (s. f.). URL https://www.gob.mx/sener/acciones-y-programas/programa-de-desarrollo-del-sistema-electrico-nacional-33462

[141] Colaborador invitado, La confiabilidad de la red eléctrica, El Financiero, accessed: 2025-11-23 (2023). URL https://www.elfinanciero.com.mx/opinion/colaborador-invitado/2023/08/17/la-confiabilidad-de-la-red-electrica/

[142] Capital 21 Web, 10.3 millones de usuarios afectados por apagón; CENACE y CFE explican causa, accessed: 2025-11-23 (2020). URL https://www.capital21.cdmx.gob.mx/noticias/?p=7009

[143] Diario Oficial de la Federación (DOF), Decreto por el que se expide la Ley General de Cambio Climático, accessed: 2025-11-23 (2012). URL https://dof.gob.mx/nota_detalle.php?codigo=5249899&fecha=06/06/201

[144] Secretaría de Energía (SENER), *Diagnóstico de Vulnerabilidad del Sector Energético ante el Cambio Climático (DVSECC)*, accessed: 2025-11-23 (s. f.). URL https://www.gob.mx/sener/articulos/diagnostico-de-vulnerabilidad-del-sector-energetico-ante-el-cambio-climatico-dvsecc-376696

[145] Centro de Investigación Económica y Presupuestaria (CIEP), *Presupuesto 2023–2024: transición energética y cambio climático*, accessed:

2025-11-23 (2024). URL https://ciep.mx/wp-content/uploads/2024/09/Presupuesto_2023_2024_TransicionEnergetica_CambioClimatico-1.pdf

[146] Secretaría de Energía (SENER), Programa Sectorial de Energía 2020–2024, accessed: 2025-11-23 (2020). URL https://www.gob.mx/cms/uploads/attachment/file/562631/PS_SENER_CACEC-DOF_08-07-2020.pdf

[147] Fundar, Centro de Análisis e Investigación, *A medio camino. Balance y pendientes de la política energética del sexenio 2018–2024*, accessed: 2025-11-23 (2022). URL https://fundar.org.mx/wp-content/uploads/2022/05/A-medio-camino-Balance-y-pendientes-de-la-politica-energetica-del-sexenio-2018-2024.pdf

[148] Secretaría de Energía (SENER), *Programa de Desarrollo del Sistema Eléctrico Nacional 2023–2037 (PRODESEN 2023–2037), Capítulo 1*, accessed: 2025-11-23 (2023). URL https://base.energia.gob.mx/PRODESEN2023/Capitulo1.pdf

[149] Cámara de Diputados del H. Congreso de la Unión, *Reglamento de la Ley de la Industria Eléctrica*, accessed: 2025-11-23 (2014). URL https://www.gob.mx/cms/uploads/attachment/file/31725/Reg_LIE.pd

[150] Cámara de Diputados del H. Congreso de la Unión, *Ley de la Industria Eléctrica*, accessed: 2025-11-23 (2014). URL https://www.gob.mx/cms/uploads/attachment/file/31722/LIElec_110814.pdf

[151] Diario Oficial de la Federación (DOF), *Acuerdo por el que se emite la Política de Confiabilidad, Seguridad, Continuidad y Calidad en el Sistema Eléctrico Nacional*, accessed: 2025-11-23 (2020). URL https://dof.gob.mx/nota_detalle.php?codigo=5593425&fecha=15/05/2020

[152] Diario Oficial de la Federación (DOF), *Decreto publicado en el Diario Oficial de la Federación relativo al sector eléctrico* (código 5752329), accessed: 2025-11-23 (2025). URL https://dof.gob.mx/nota_detalle.php?codigo=5752329&fecha=18/03/2025#gsc.tab=0

[153] J. de la Cruz-Soto, I. Azkona-Bedia, N. Vel´azquez-Lim´on, T. Romero-Casta˜n´on, A techno-economic study for a hydrogen storage system in a microgrid located in baja california, mexico: Levelized cost of energy for power to gas to power scenarios, International Journal of Hydrogen Energy 47 (70) (2022) 30050–30061. doi:10.1016/j.ijhydene.2022.03.026.

[154] IMARC Group, Mexico microgrid market: Industry trends, share, size, growth, opportunity and forecast 2025-2033, accessed: 2025-05-24

(2024). URL https://www.imarcgroup.com/mexico-microgrid-market

[155] Mexico Business News, Cre publishes regulatory framework for energy storage in mexico, accessed: 2025-05-24 (March 2025). URL https://mexicobusiness.news/energy/news/cre-publishes regulatory-framework-energy-storage-mexico

[156] W. Bank, Stronger power: Improving power sector resilience to natural hazards, Tech. rep., World Bank (2019). URL https://documents1.worldbank.org/curated/en/200771560790885170/ pdf/Stronger-Power-Improving-Power-Sector-Resilience-to-Natural Hazards.pdf

[157] Green Climate Fund. (n.d.). *About the Green Climate Fund*. https://www.greenclimate.fund/about

[158] Green Climate Fund. (n.d.). *United Mexican States*. https://www.greenclimate.fund/countries/mexico

[159] Secretaría de Energía (SENER), *Informe consolidado IGG – Secretaría de Energía*, accessed: 2025-11-23 (2024). URL https://www.gob.mx/cms/uploads/attachment/file/944927/Informe_Consolidado_IGG_SENER_30_08_2024_CS.pdf

[160] Ministry for the Environment. (2025). *National policy statement for renewable electricity generation*. https://environment.govt.nz/acts-and-regulations/national-policy-statements/national-policy-statement-for-renewable-electricity-generation

[161] Ministry for the Environment. (2022). *Aotearoa New Zealand's first emissions reduction plan: Chapter 11—Energy and industry*. https://environment.govt.nz/assets/Emissions-reduction-plan-chapter-11-energy-and-industry.pdf

[162] New Zealand Government. (2010). *Electricity Industry Act 2010*. https://www.legislation.govt.nz/act/public/2010/0116/latest/DLM2634233.html

[163] Ministry of Business, Innovation & Employment. (2010). *Electricity industry regulatory framework*. https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-generation-and-markets/electricity-market/electricity-industry-regulatory-framework

[164] Transpower New Zealand. (2024). *Adaptation plan: Climate adaptation plan for the transmission system*. https://www.transpower.co.nz/about-us/sustainability/adaptation-plan

[165] Ministry for the Environment. (2022). *Urutau, ka taurikura: Kia tū*

pakari a Aotearoa i ngā huringa āhuarangi – Adapt and thrive: Building a climate-resilient New Zealand (National adaptation plan 2022–28). https://environment.govt.nz/assets/publications/climate-change/MFE-AoG-20664-GF-National-Adaptation-Plan-2022-WEB.pdf

[166] Ministry of Business, Innovation & Employment. (2023). *Advancing New Zealand's energy transition: Context document to inform the New Zealand energy strategy*. https://www.ena.org.nz/assets/9927-Advancing-New-Zealands-Energy-Transition-AUG23.pdf

[167] National Emergency Management Agency. (2025). *National disaster resilience strategy: Summary version*. https://www.civildefence.govt.nz/cdem-sector/plans-and-strategies/national-disaster-resilience-strategy/national-disaster-resilience-strategy-summary-version

[168] New Zealand Infrastructure Commission (Te Waihanga). (2025). *Draft national infrastructure plan*. https://media.umbraco.io/te-waihanga-30-year-strategy/mepk0cfb/nip-draft-layout-28aug.pdf

[169] New Zealand Treasury. (2023). *Budget policy statement 2023*. https://www.treasury.govt.nz/sites/default/files/2022-12/bps23_2.pdf

[170] New Zealand Infrastructure Commission (Te Waihanga). (2023). *Infrastructure action plan 2023*. https://www.treasury.govt.nz/sites/default/files/2023-05/infrastructure-action-plan-2023.pdf

[171] Ministry for the Environment. (2022). *Aotearoa New Zealand's first national adaptation plan*. https://environment.govt.nz/assets/publications/climate-change/MFE-AoG-20664-GF-National-Adaptation-Plan-2022-WEB.pdf

[172] Transpower New Zealand. (2023). *Transmission planning report 2023*. https://static.transpower.co.nz/public/uncontrolled_docs/Transmission%20Planning%20Report%202023.pdf

[173] Commerce Commission. (2024). *Total electricity distribution performance summary: Year to 31 March 2024*. https://www.comcom.govt.nz/assets/pdf_file/0034/367198/Total-electricity-distribution-Year-to-31-March-2024.pdf

[174] Commerce Commission. (2024). *Explanatory notes for electricity distributors' performance summaries*. https://www.comcom.govt.nz/assets/pdf_file/0023/320468/Explanatory-

notes-for-electricity-distributors-performance-summaries.pdf

[175] Electricity Authority, & Transpower New Zealand. (2021). *Opportunities and challenges to the future security and resilience of the New Zealand power system: Future security and resilience (FSR) programme, Phase 1 draft report*. https://www.ea.govt.nz/documents/1916/02-FSR-Phase-1-draft-report-Nov-2021-v2.1332512.1.pdf

[176] International Monetary Fund (IMF), Fiscal Affairs Department, Papua New Guinea: Climate Policy Diagnostic – Technical Assistance Report, accessed: 2025-11-23 (2024). URL: /mnt/data/3005-4575-019.2025.issue-025-en.pdf

[177] World Bank, World Bank Announces Transformative Energy Access Project to Benefit 400,000 Papua New Guineans, accessed: 2025-11-24 (2024). URL https://www.worldbank.org/en/news/press-release/2024/11/29/world-bank-announces-transformative-energy-access-project-to-benefit-400-000-papua-new-guineans

[178] Global Green Growth Institute (GGGI), Australian Funded AUD 20 MILLION PNG CLIMATE FIRST Project Launched, accessed: 2025-11-24 (2024). URL https://gggi.org/climate-first-project-launched/

[179] Asian Development Bank, Papua new guinea: Power sector development project sector assessment (summary): Energy, accessed: 2025-05-08 (2023). URL https://www.adb.org/sites/default/files/linked-documents/47356 002-ssa.pdf

[180] Sinalda, Voltage and power quality in papua new guinea, accessed: 2025-05-08 (2021). URL https://www.sinalda.com/world-voltages/oceania/voltage-papua new-guinea/#:˜:text=Power%20Quality%20in%20Papua%20New,outages%20and%20brownouts%20are%20frequent.

[181] Jubilee Australia, Png's energy policy and practise for climate and people: Building on what works, accessed: 2025-05-08 (2023). URLhttps://www.jubileeaustralia.org/storage/app/uploads/public/63c/daa/f1f/63cdaaf1f37ff165892315.pdf

[182] Davies, Martin; Lohberger, Christian, Electrifying PNG: challenges and opportunities for decentralised solar, accessed: 2025-11-24 (2025). URL https://devpolicy.org/electrifying-png-challenges-and-opportunities-for-decentralised-solar-20250516/

[183] Comité de Operación Económica del Sistema Interconectado Nacional (COES), *¿Quiénes somos?*, accessed: 2025-11-24 (s/f). URL https://www.coes.org.pe/Portal/Organizacion/QuienesSomos

[184] Ministerio de Energía y Minas (MINEM), *Anuario Estadístico de Electricidad 2020*, accessed: 2025-11-24 (2023). URL https://www.gob.pe/institucion/minem/informes-publicaciones/4742666-anuario-estadistico-de-electricidad-2020

[185] Ministerio de Energía y Minas (MINEM), *Política Energética Nacional del Perú 2010–2040*, Decreto Supremo N.° 064-2010-EM, accessed: 2025-11-23 (2010). URL https://www.osinergmin.gob.pe/seccion/centro_documental/PlantillaMarcoLegalBusqueda/DS-064-2010-EM.pdf

[186] Ministerio de Energía y Minas (MINEM), *Plan Energético Nacional 2014–2025*, accessed: 2025-11-23 (2014). URL https://www.gob.pe/institucion/minem/informes-publicaciones/4821287-plan-energetico-nacional-2014-2025

[187] Congreso de la República del Perú, *Ley 30754: Ley Marco sobre Cambio Climático*, accessed: 2025-11-23 (2018). URL https://busquedas.elperuano.pe/dispositivo/NL/1638161-1

[188] Ministerio del Ambiente (MINAM), *Decreto Supremo N.° 003-2022-MINAM que declara de interés nacional la emergencia climática*, accessed: 2025-11-23 (2022). URL https://busquedas.elperuano.pe/dispositivo/NL/2033317-1

[189] Ministerio de Energía y Minas (MINEM), *Norma Técnica de Calidad de los Servicios Eléctricos (NTCSE)*, Decreto Supremo N.° 020-97-EM, accessed: 2025-11-23 (1997). URL https://www.osinergmin.gob.pe/cartas/documentos/electricidad/normativa/NTCSE_DS020-97-EM.pdf

[190] Organismo Supervisor de la Inversión en Energía y Minería (Osinergmin), *Supervisión de la Norma Técnica de Calidad de los Servicios Eléctricos (NTCSE)*, accessed: 2025-11-23 (s. f.). URL https://www.osinergmin.gob.pe/empresas/electricidad/calidad/NTCSE

[191] Organismo Supervisor de la Inversión en Energía y Minería (Osinergmin), *4.4. Reporte de interrupciones del servicio eléctrico. Supervisión de los sistemas eléctricos – Interrupciones*, accessed: 2025-11-24 (2025). URL https://rendiciondecuentas.osinergmin.gob.pe/Archivos/2025/Osinergmin-DRC-EL-reporte-interrupciones-servicio-2025-I.pdf

[192] Organismo Supervisor de la Inversión en Energía y Minería (Osinergmin), *Reporte Gerencial Especial de Eventos Relevantes N° 889 para el Consejo Directivo (29 de marzo al 4 de abril de 2023)*, accessed: 2025-11-24 (2023). URL

https://www.osinergmin.gob.pe/seccion/centro_documental/electricidad/Documentos/Reportes/Osinergmin-DSE-RGE-CD-889-29-03-04-04-2023.pdf

[193] Ministerio de Economía y Finanzas (MEF). (2019). *Plan nacional de infraestructura para la competitividad*. Gobierno del Perú. https://www.mef.gob.pe/contenidos/inv_privada/planes/PNIC_2019.pdf

[194] Ministerio de Economía y Finanzas (MEF). (2022). *Plan nacional de infraestructura sostenible para la competitividad 2022–2025*. Gobierno del Perú. https://www.mef.gob.pe/contenidos/inv_privada/planes/PNISC_2022_2025_V2.pdf

[195] Ministerio del Ambiente (MINAM). (2021). *Estrategia nacional ante el cambio climático al 2050*. Gobierno del Perú. https://cdn.www.gob.pe/uploads/document/file/7767750/6562767-politica-nacional-estrategia-nacional-ante-cambio-climatico-al-2050.pdf

[196] World Bank. (2021). *Peru transmission investment plan (PIT) to support post-COVID-19 green economic recovery in Peru*. https://documents1.worldbank.org/curated/en/099120325162012883/pdf/P174812-af46a042-c0c4-45b5-985b-39abaaa338fd.pdf

[197] Ministerio del Ambiente (MINAM), *Plan Nacional de Adaptación al Cambio Climático del Perú: un insumo para la actualización de la Estrategia Nacional ante el Cambio Climático*, Resolución Ministerial N.° 096-2021-MINAM, accessed: 2025-11-23 (2021). URL https://www.gob.pe/institucion/minam/normas-legales/1955977-096-2021-minam

[198] Department of Energy (Philippines). (2023). Philippine Energy Plan 2023-2050: Volume II. https://legacy.doe.gov.ph/sites/default/files/pdf/pep/PEP%202023-2050%20Vol.%20II.pdf

[199] Department of Energy (Philippines). (2023). Philippine Energy Plan 2023-2050: Volume III. https://legacy.doe.gov.ph/sites/default/files/pdf/pep/PEP%202023-2050%20Vol.%20III_0.pdf

[200] Department of Energy (Philippines). (2023). Philippine Energy Plan 2023-2050: Volume I. https://legacy.doe.gov.ph/sites/default/files/pdf/pep/PEP%202023-2050%20Vol.%20I.pdf

[201] Lee, E., Böer, B., Surendra, L., Chun, J. A., & Taniguchi, M. (2024). Chapter 3. In The water, energy, and food security nexus in Asia and the

Pacific: East and Southeast Asia (pp. ___). Springer. https://link.springer.com/chapter/10.1007/978-3-031-12495-2_3

[202] Republic of the Philippines. (2018). Republic Act No. 11039: An Act institutionalizing the Electric Cooperatives Emergency and Resiliency Fund and appropriating funds therefor. https://lawphil.net/statutes/repacts/ra2018/ra_11039_2018.html

[203] Southeast Asia Infrastructure. (2024, July 1). Philippines' power sector: Focus on transmission to interconnect RES and islands. https://southeastasiainfra.com/philippines-power-sector-focus-on-transmission-to-interconnect-res-and-islands/

[204] CIGRE Russian National Committee, *Unified Energy System of Russia – The Electric Power System*, accessed: 2025-11-24 (2014). URL https://www.cigre.org/userfiles/files/Community/NC/Russia_The_Electric_Power_System.pdf

[205] International Renewable Energy Agency (IRENA), *Russian Federation – Renewable Energy Statistical Profile*, accessed: 2025-11-24 (2025). URL https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Eurasia/Russian-Federation_Eurasia_RE_SP.pdf

[206] Federación de Rusia, *Ley Federal N.º 35-FZ de 26 de marzo de 2003 "Sobre la industria eléctrica"*, accessed: 2025-11-23 (2003).

[207] Ministry of Energy of the Russian Federation, *Energy Security Doctrine of the Russian Federation*, accessed: 2025-11-23 (2019). URL https://minenergo.gov.ru/ministry/energy-security-doctrine

[208] Government of the Russian Federation, *Energy Strategy of the Russian Federation until 2035*, Asia Pacific Energy Portal, accessed: 2025-11-23 (2020). URL https://policy.asiapacificenergy.org/node/1240

[209] World Bank, *Doing Business 2020: Russian Federation. Getting Electricity – Measure of Quality (SAIDI and SAIFI)*, accessed: 2025-11-24 (2020). URL https://archive.doingbusiness.org/content/dam/doingBusiness/country/r/russia/RUS.pdf

[210] System Operator of the Unified Energy System (SO UPS), *Report on the functioning of the Unified Energy System of Russia in 2023 (based on operational data)*, accessed: 2025-11-24 (2024). URL https://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2024/ups_rep2023.pdf

[211] Government of the Russian Federation, *National Action Plan for the First Phase of Adaptation to Climate Change (approved by Order of*

December 25, 2019 No. 3183-r), accessed: 2025-11-23 (2019). URL https://climate-laws.org/document/national-action-plan-for-the-first-phase-of-adaptation-to-climate-change-approved-by-order-of-december-25-2019-no-3183-r_2882

[212] Gobierno de la Federación de Rusia, *Orden N.º 3052-r de 29 de octubre de 2021 "Sobre la aprobación de la Estrategia de desarrollo socioeconómico de la Federación de Rusia con bajas emisiones de gases de efecto invernadero hasta 2050"*, accessed: 2025-11-23 (2021).

[213] United Nations Environment Programme (UNEP) / FAOLEX, *Presidential Decree No. 812 validating the Climate Doctrine of the Russian Federation*, accessed: 2025-11-23 (2023) URL https://leap.unep.org/en/countries/ru/national-legislation/presidential-decree-no-812-validating-climate-doctrine-russian

[214] Russian Federation, *Nationally Determined Contribution of the Russian Federation*, submitted under the UNFCCC, accessed: 2025-11-23 (2020). URL https://unfccc.int/sites/default/files/NDC/2022-06/NDC_RF_eng.pdf

[215] Russian Federation. (2020). *Energy strategy of the Russian Federation for the period up to 2035* [Decree No. 1523-r]. Government of the Russian Federation. http://static.government.ru/media/files/w4sigFOiDjGVDYT4IgsApssm6mZRb7wx.pdf

[216] World Bank. (2020). *Doing business 2020: Economy profile of the Russian Federation*. World Bank Group. https://archive.doingbusiness.org/content/dam/doingBusiness/country/r/russia/RUS.pdf

[217] Peh Hui Ting, Natania, Building Ecological Resilience in Singapore's Electricity System to Adapt to Climate Change, accessed: 2025-11-20 (2025). URL https://www.singaporelawreview.com/juris-illuminae-entries/2025/building-ecological-resilience-in-singapores-electricity-system-to-adapt-to-climate-change

[218] SP Group, Always Here for You, accessed: 2025-11-20 (s.f.). URL https://www.spgroup.com.sg/about-us/media-resources/energy-hub/reliability/always-here-for-you

[219] Energy Market Authority (EMA), Four Switches for Singapore's Energy Transition, accessed: 2025-11-20 (2024). URL https://www.ema.gov.sg/resources/corporate-publications/annual-sustainability-report-2023-2024/four-switches-for-sg-energy-transition

[220] Thian, Si Ying, EMA eyes GenAI and predictive analytics to strengthen Singapore's energy resilience, accessed: 2025-11-20 (2025). URL https://govinsider.asia/intl-en/article/ema-eyes-genai-and-predictive-analytics-to-strengthen-singapores-energy-resilience

[221] Energy Market Authority (EMA), Regulatory Sandbox, accessed: 2025-11-20 (s.f.). URL https://www.ema.gov.sg/regulations-licences/regulations/policies-frameworks/regulatory-sandbox

[222] International Trade Administration, Singapore – Energy, accessed: 2025-11-20 (2024). URL https://www.trade.gov/country-commercial-guides/singapore-energy#:~:text=El%20gas%20natural%20representa%20m%C3%A1s,centro%20de%20abastecimiento%20de%20GNL

[223] Mordor Intelligence, Singapore Renewable Energy Market, accessed: 2025-11-20 (2025). URL https://www.mordorintelligence.ar/industry-reports/singapore-renewable-energy-market#:~:text=Se%20espera%20que%20el%20mercado%20de%20energ%C3%ADa,las%20principales%20empresas%20que%20operan%20en%20este

[224] Sinalda UK Limited. (2024, June 13). Voltage in Taiwan: Electricity supply and power quality overview. https://www.sinalda.com/world-voltages/asia/voltage-taiwan

[225] European Chamber of Commerce Taiwan. (2025, January 20). Taiwan's energy transition outlook for 2025. EUROVIEW. https://euroview.ecct.com.tw/category-inside.php?id=2247

[226] Taiwan (China). (2021, July 16). Disaster prevention and response act NationallawNational lawNationallaw. PreventionWeb. https://www.preventionweb.net/files/59947_chinataiwan.pdf

[227] Asuka, J., & Jin, D. (Eds.). (2022). Energy transition and energy democracy in East Asia. Springer Singapore. https://doi.org/10.1007/978-981-19-0280-2

[228] Taiwan Power Company. (2022). *Taipower launches 10-year grid resilience strengthening construction plan*. https://www.taipower.com.tw/2764/2804/2805/24982/normalPost

[229] Ministry of Economic Affairs (MOEA), Chinese Taipei. (2023). *MOEA supports Taipower's grid resilience and system reinforcement plan*. https://www.moea.gov.tw/Mns/english/news/News.aspx?kind=6&menu_id=176&news_id=121125

[230] Climate Change Administration, Executive Yuan, Chinese Taipei.

(2023). *Adaptation and resilience*. https://www.cca.gov.tw/en/affairs/adaptation-and-resilience/1995.html

[231] Ministry of Economic Affairs (MOEA), Chinese Taipei. (2023). *Strengthening power system resilience and supply stability*. https://www.moea.gov.tw/MNS/english/news/News.aspx?kind=6&menu_id=176&news_id=121380

[232] Taiwan Power Company. (2023). *2023 sustainability report: Quality electricity service*. Taiwan Power Company. https://www.taipower.com.tw/mag/Sustainability_en/2023sustainability.pdf

[233] Gao, A. M.-Z., Fan, C.-T., & Chen, J.-S. (2020). A critical review of the world's first renewable portfolio standard (RPS) for large electricity users in Taiwan: The return of the RPS? Energy Strategy Reviews, 32, 100585. https://doi.org/10.1016/j.esr.2020.100585

[234] ASEAN Centre for Energy (ACE), 8th ASEAN Energy Outlook 2023–2050, accessed: 2025-11-20 (2024). URL https://aseanenergy.org/wp-content/uploads/2024/09/8th-ASEAN-Energy-Outlook.pdf

[235] International Trade Administration, Thailand Energy and Climate, accessed: 2025-11-21 (2023). URL https://www.trade.gov/market-intelligence/thailand-energy-and-climate#:~:text=El%20plan%20busca%20mejorar%20la,utilizaci%C3%B3n%20y%20almacenamiento%20de%20carbono

[236] National Energy Policy Committee, Resolution on additional renewable fit quotas, Government resolution (Mar. 2023).

[237] Energy Regulatory Commission, Framework guideline on third-party access, Reg ulatory guideline (2024).

[238] Department of Alternative Energy Development and Efficiency, Alternative energy development plan 2018–2037, Tech. rep., Ministry of Energy, Bangkok (2020).

[239] Organisation for Economic Co-operation and Development, Clean energy finance and investment roadmap of thailand, Tech. rep., OECD, Paris (2024).

[240] Metropolitan Electricity Authority (MEA), Reliability Indices, accessed: 2025-11-21 (s.f.). URL https://www.mea.or.th/en/statistics/reliability-indice

[241] Electricity Generating Authority of Thailand (EGAT), The World's Largest Hydro-Floating Solar Hybrid, accessed: 2025-11-22 (s.f.). URL https://www.egat.co.th/home/en/the-worlds-largest-hydro-floating-solar-

hybrid/

[242] Bangkok Post, EGAT aims to turn hydropower dams into giant batteries, accessed: 2025-11-22 (2024). URL https://www.bangkokpost.com/business/general/2898406/egat-aims-to-turn-hydropower-dams-into-giant-batteries

[243] Green Climate Fund. (n.d.). Kingdom of Thailand. https://www.greenclimate.fund/countries/thailand

[244] Asian Development Bank. (2024). Thailand: Member Fact Sheet. https://www.adb.org/sites/default/files/publication/27802/tha-2024.pdf

[245] United States Congress. (2021). *Infrastructure Investment and Jobs Act* (Pub. L. No. 117–58). U.S. Government Publishing Office. https://www.govinfo.gov/app/details/PLAW-117publ58

[246] North American Electric Reliability Corporation, Reliability Issues Steering Committee. (2018). *Resilience framework: RISC resilience report*. https://www.nerc.com/comm/RISC/Related%20Files%20DL/RISC%20Resilience%20Report_Approved_RISC_Committee_November_8_2018_Board_Accepted.pdf

[247] North American Electric Reliability Corporation. (2024). *Reliability Issues Steering Committee charter*. https://www.nerc.com/comm/RISC/Related%20Files%20DL/RISC_Charter_aprvd_12102024.pdf

[248] The White House. (2023). *National cybersecurity strategy*. Executive Office of the President. https://bidenwhitehouse.archives.gov/wp-content/uploads/2023/03/National-Cybersecurity-Strategy-2023.pdf

[249] U.S. Government Accountability Office. (2023). *Critical infrastructure protection: National cybersecurity strategy needs to address information sharing performance measures and methods* (GAO-23-105468). https://www.gao.gov/products/gao-23-105468

[250] The White House. (2024). *National security memorandum on critical infrastructure security and resilience (NSM-22)*. Executive Office of the President. https://www.cisa.gov/national-security-memorandum-critical-infrastructure-security-and-resilience

[251] U.S. Department of Energy, Grid Deployment Office. (2025). *Grid resilience and innovation partnerships (GRIP) program*. https://www.energy.gov/gdo/grid-resilience-and-innovation-partnerships-grip-program

[252] U.S. Department of Energy, Grid Deployment Office. (2025). *Grid*

resilience and innovation partnerships (GRIP) program – Projects. https://www.energy.gov/gdo/grid-resilience-and-innovation-partnerships-grip-program-projects

[253] U.S. Department of Energy, National Energy Technology Laboratory. (2022). *BIL grid resilience and innovation partnerships (GRIP)*. https://netl.doe.gov/node/12202

[254] U.S. Department of Energy, Grid Deployment Office. (2025). *Grid resilience state/tribal formula grants program*. https://www.energy.gov/gdo/grid-resilience-statetribal-formula-grants-program

[255] U.S. Department of Energy, National Energy Technology Laboratory. (2024). *Grid resilience state and tribal formula grants*. https://netl.doe.gov/iijahub/grid-resilience/formula-grants

[256] U.S. Department of Energy, Grid Deployment Office, & National Energy Technology Laboratory. (2022). *Grid resilience formula grants – Section 40101(d) webinar* [Webinar slides]. https://www.energy.gov/sites/default/files/2022-05/Grid-Resilience%2040101d%20Webinar%20Final%20(web).pdf

[257] U.S. Congress. (2021). *Infrastructure Investment and Jobs Act* (Pub. L. No. 117-58). https://www.govinfo.gov/content/pkg/PLAW-117publ58/pdf/PLAW-117publ58.pdf

[258] U.S. Congress. (2022). *Inflation Reduction Act of 2022* (Pub. L. No. 117-169). https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf

[259] Congressional Research Service. (2025). *FEMA's Building Resilient Infrastructure and Communities (BRIC) program: Recent developments* (CRS Insight IN12609). https://www.congress.gov/crs-product/IN12609

[260] U.S. Department of Energy, Grid Deployment Office. (2024). *Biennial Report to Congress: Preventing Outages and Enhancing the Resilience of the Electric Grid.* https://www.energy.gov/sites/default/files/2024-08/EXEC-2023-003585%20-%20Congressional%20Report%20on%20Preventing%20Outages%20and%20Enhancing%20the%20Resilience%20of%20the%20Electric%20Grid_sb-S1_7.1.pdf

[261] U.S. Department of Energy, Grid Deployment Office. (2023). *Grid resilience and innovation partnerships (GRIP) program*.

https://www.energy.gov/gdo/grid-resilience-and-innovation-partnerships-grip-program

[262] U.S. Energy Information Administration. (2025). *Electric power annual 2024: Reliability metrics of U.S. electricity distribution systems (Table 11.3)*. https://www.eia.gov/electricity/annual/html/epa_11_03.html

[263] U.S. Department of Energy, Office of Cybersecurity, Energy Security, and Emergency Response. (2025). *Office of Cybersecurity, Energy Security, and Emergency Response (CESER): About / mission*. https://www.energy.gov/ceser/office-cybersecurity-energy-security-and-emergency-response

[264] International Trade Administration, Vietnam – Power Generation, Transmission, and Distribution, accessed: 2025-11-22 (2024). URL https://www.trade.gov/country-commercial-guides/vietnam-power-generation-transmission-and-distribution

[265] Electricity and Renewable Energy Authority (EREA), Politburo's new resolution aims to ensure energy security for national development in new era, accessed: 2025-11-22 (2024). URL https://www.eav.gov.vn/d/en-US/news-o/Politburos-new-resolution-aims-to-ensure-energy-security-for-national-development-in-new-era-60-108-58617

[266] Valeri, S.; de Groot, R.; Friggens, S.; Hulbert, P., Future of Electricity – Vietnam – Building Resilience for Vietnam's Power System (A Cross-cutting Report), accessed 2025-11-23 (2024). URL https://static1.squarespace.com/static/5a9d042e3917eeb31ce746e7/t/66ecf85f60656268a0ad9f46/1726806128245/7.+EN-Resilience+CRR.pdf

[267] Vietnam Electricity (EVN), EVN's business and customer service activities in 2024 achieve many positive outcomes, accessed: 2025-11-25 (2024). URL https://en.evn.com.vn/d/en-US/news/EVNs-business-and-customer-service-activities-in-2024-achieve-many-positive-outcomes-60-204-500388

[268] Vietnam.vn, Vẫn còn hơn 237.000 khách hàng đang mất điện do mưa lũ, accessed: 2025-11-25 (2025). URL https://www.vietnam.vn/es/van-con-hon-237-000-khach-hang-dang-mat-dien-do-mua-lu

[269] Energy Transition Partnership, Managing vietnam's grid issues for effective energy transition, accessed: 2025-05-08 (2023). URL https://www.energytransitionpartnership.org/wp-content/uploads/2024/06/Managing-Vietnams-Grid-Issues-for-Effective-Energy Transition.pdf

[270] D. Hutt, Why are european renewable giants fleeing vietnam?,

accessed: 2025-05 08 (2024). URL https://www.dw.com/en/why-are-european-renewable-giants fleeing-vietnam/a-70309674

[271] Vietnam Government Portal, Ký kết gói thầu hơn 4.300 tỉ đồng cho thủy điện tích năng đầu tiên của Việt Nam, accessed: 2025-11-22 (2025). URL https://www.vietnam.vn/en/ky-ket-goi-thau-hon-4-300-ti-dong-cho-thuy-dien-tich-nang-dau-tien-cua-viet-nam