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Economic Cooperation

Identification of Emerging Signals Affecting Carbon Neutrality in APEC Using Foresight

APEC Policy Partnership for Science, Technology and Innovation

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Executive Summary

The Asia-Pacific Economic Cooperation (APEC) region sits at the center of the global carbon neutrality challenge. Accounting for more than 60 percent of global greenhouse gas (GHG) emissions and over half of global economic output, APEC's trajectory will significantly influence whether international climate targets are achieved. Yet the region's diversity—in development stages, governance systems, energy structures, and economic priorities—makes carbon neutrality both urgent and complex. This report addresses a critical policy gap: while most APEC economies have announced long-term net-zero ambitions, less attention has been given to identifying emerging developments that could accelerate, reshape, or disrupt these pathways. Technological breakthroughs, geopolitical shifts, social dynamics, and financial innovation are rapidly altering the landscape of decarbonization. Policymaking that relies solely on past trends risks being reactive rather than strategic.

The project *Identification of Emerging Signals Affecting Carbon Neutrality in APEC Using Foresight* was developed to enhance forward-looking decision-making across the region. It combines:

- Comprehensive review of structural challenges,
- Horizon scanning to identify emerging signals,
- Expert survey validation across APEC economies,
- Participatory foresight workshop processes, and
- A structured policy interpretation framework.

This approach strengthens decision-making under uncertainty. Rather than assuming linear progress, it prepares policymakers to respond proactively to accelerating innovation, environmental stress, and political economy dynamics. The objective is not to predict a single future, but to improve preparedness under uncertainty and strengthen strategic coordination across economies.

Structural Realities Shaping the Transition

The analysis confirms that APEC economies face six interconnected structural constraints that shape the feasibility and pace of decarbonization:

- *Governance and policy fragmentation:* While many economies have announced climate targets, implementation frameworks vary widely in legal strength, institutional coordination, and long-term durability. Policy volatility can undermine investor confidence and slow infrastructure development.
- *Fossil fuel lock-in and infrastructure limitations:* Existing coal, oil, and gas infrastructure, combined with grid bottlenecks and storage gaps, creates structural inertia that delays renewable integration and electrification.
- *Climate finance gaps:* Investment requirements far exceed current flows, particularly in developing economies where fiscal constraints and higher capital costs limit access to financing.
- *Hard-to-abate sector emissions:* Heavy industry, long-distance transport, aviation, and shipping require breakthrough technologies and significant capital expenditure.

- *Social equity and just transition pressures:* Workforce displacement, regional economic disruption, and energy affordability concerns can generate political resistance if not managed carefully.
- *Data, MRV, and institutional capacity limitations:* Weak monitoring systems constrain transparency, limit participation in carbon markets, and reduce access to climate finance.

These structural barriers are interdependent. For example, insufficient MRV capacity reduces credibility in international finance markets; weak governance frameworks discourage long-term infrastructure investment; and social resistance can stall carbon pricing or subsidy reform. Effective transition strategies must therefore integrate institutional reform, financial mobilization, technological deployment, and social protection.

Emerging Signals: What Could Reshape the Pathway?

Horizon scanning revealed a dynamic ecosystem of emerging signals across multiple domains. Some are already reshaping policy landscapes:

- *Electrified mobility expansion*, driven by EV adoption mandates, battery ecosystem development, and corporate procurement strategies, is accelerating transformation in the transport sector.
- *Smart grid modernization and regional grid integration* are enhancing renewable energy penetration while improving system resilience.
- *Integrated MRV-data platforms* are strengthening transparency, enabling performance tracking, and unlocking climate finance access.
- *Food insecurity and global water stress* are rising in urgency, highlighting the inseparability of mitigation and adaptation agendas.
- *Worker reskilling and transition programs* are emerging as central components of equitable decarbonization strategies.

Simultaneously, frontier signals—such as CCUS-as-a-service models, hydrogen diplomacy, advanced nuclear technologies, circular economy innovations, and alternative protein systems—could significantly alter industrial and energy systems over the long term. While their pathways remain uncertain, early strategic engagement can reduce risk and enhance preparedness.

Survey validation across APEC economies confirms that food–water security, EV ecosystem expansion, and integrated MRV systems rank highest in combined impact, likelihood, and urgency. Political economy factors—including energy pricing sensitivity and anti-carbon tax movements—also score highly, underscoring that societal acceptance and political stability are as decisive as technological innovation.

From Signals to Strategy: Policy Response Architecture

To translate foresight findings into policy guidance, the report proposes a structured response framework that aligns signals with differentiated action pathways:

- **Accelerate where urgency and feasibility align:** Immediate action is required for EV ecosystem scaling, grid modernization, food–water resilience measures, and robust MRV system deployment.
- **Integrate emerging pathways into medium-term planning:** Hydrogen systems, battery circularity, sustainable fuels, and transition finance instruments should be embedded in strategic development plans.

- **Mitigate political and social risks proactively:** Safeguards addressing energy affordability, targeted compensation schemes, and transparent communication are essential to prevent backlash.
- **Invest in preparedness for breakthrough technologies:** Dedicated R&D funding, demonstration projects, and regulatory readiness will reduce uncertainty for frontier innovations.
- **Institutionalize systematic monitoring mechanisms:** Continuous tracking of weak signals enables early detection of disruptive acceleration or emerging risks.

This differentiated framework allows policymakers to prioritize resources effectively while maintaining adaptive flexibility in a rapidly evolving landscape.

Strategic Implications for APEC

Three strategic implications stand out:

1) **Carbon neutrality is a systems transformation.** Energy policy alone is insufficient; governance reform, financial architecture, industrial competitiveness, and social cohesion are equally critical.
2) **Resilience and mitigation are mutually reinforcing.** Food security, water systems, biodiversity protection, and public health must be integrated into climate strategies to sustain economic stability.
3) **Regional cooperation enhances efficiency and reduces fragmentation.** Cross-border dynamics—such as hydrogen trade corridors, mineral supply chains, carbon border measures, and grid interconnection—require harmonized standards and coordinated policy dialogue under APEC platforms.

Carbon neutrality in the Asia-Pacific will be achieved not only through technological innovation but through anticipatory governance. By embedding foresight into policy processes, APEC economies can better manage uncertainty, reduce fragmentation, and align short-term actions with long-term transformation.

This report provides both an analytical lens and a strategic toolkit. It supports APEC members in identifying where immediate action is required, where strategic patience is warranted, and where collaborative leadership can unlock systemic progress. In doing so, it strengthens the region's collective capacity to deliver a low-carbon transition that is economically resilient, socially inclusive, and globally consequential.

1 Introduction

Carbon neutrality has become a defining strategic objective for the global community, and the Asia-Pacific Economic Cooperation (APEC) region plays a decisive role in determining its success. APEC economies collectively account for more than 60 percent of global greenhouse gas (GHG) emissions and over 60 percent of global GDP. The region's transition toward carbon neutrality will therefore strongly influence whether the Paris Agreement goals can be achieved.

Over the past decade, most APEC economies have announced long-term carbon neutrality aspirations, many targeting mid-century. While progress is visible—particularly in renewable energy expansion, electric mobility, and climate finance innovation—significant structural challenges persist. These include gaps in policy and governance frameworks, continued fossil fuel dependency, infrastructure and technology bottlenecks, insufficient climate finance mobilization, sectoral decarbonization barriers in industry and transport, social and just transition concerns, and weaknesses in data and measurement, reporting, and verification (MRV) systems. The diversity of economic structures and development stages across APEC further complicates coordinated implementation.

In this context, traditional policy planning based solely on existing trends may be insufficient. The pathway to carbon neutrality is increasingly shaped by emerging dynamics—technological breakthroughs, geopolitical shifts, financial innovation, evolving social expectations, and environmental stressors—that may accelerate or disrupt progress. Early identification of such developments is critical to strengthening resilience and strategic preparedness.

This project, *Identification of Emerging Signals Affecting Carbon Neutrality in APEC Using Foresight*, was initiated under APEC PPSTI 211 2024A to enhance anticipatory capacity across member economies. Using a structured foresight framework, the project systematically identifies "emerging signals"—early indications of change that may significantly influence carbon neutrality trajectories. These signals were detected through literature review and horizon scanning, validated through expert surveys, and refined through participatory foresight workshops.

The report pursues three objectives. First, it reviews key structural challenges confronting APEC economies in achieving carbon neutrality. Second, it maps and categorizes emerging signals across thematic domains, including technology-driven transition, nature and societal resilience, and enabling governance and financial frameworks. Third, it translates these findings into strategic insights to inform adaptive and forward-looking policy responses.

By integrating signal detection into policy reflection, this report supports APEC economies in navigating uncertainty and enhancing regional cooperation. Carbon neutrality is not only an environmental target; it is a transformative development agenda that reshapes energy systems, industries, labor markets, and financial architectures. Strengthening foresight capabilities will be essential for ensuring that the region's transition is timely, inclusive, and resilient.

2 Foresight Methodologies

This project adopts a foresight-oriented research methodology designed to strengthen the capacity of APEC economies to anticipate and prepare for emerging challenges and opportunities on the path toward carbon neutrality. The methodology integrates evidence-based research, stakeholder engagement, and participatory foresight tools, structured in the following steps:

1) **Literature Review and Challenge Mapping**
   A comprehensive desk review of academic studies, policy documents, and technical reports was conducted to identify the key challenges faced by APEC economies in pursuing carbon neutrality. These challenges span six domains: policy and governance, energy transition and technology, finance and investment, industry and transport decarbonization, social and just transition, and data/MRV capacity. This provided a foundation for linking existing obstacles with potential emerging signals.

2) **Identification of Emerging Signals**
   Horizon scanning techniques were applied to detect weak but observable signs of change—emerging signals—that may evolve into transformative drivers. Signals were classified under thematic categories consistent with the identified challenge areas, including governance reforms, clean energy innovation, financial instruments, industrial transitions, social dynamics, and data governance.

3) **Survey Validation Across APEC Economies**
   An online survey was distributed to representatives from APEC economies to validate the relevance, importance, and potential impact of the identified signals. This process ensured that the signals reflected both expert judgment and regional perspectives, while helping prioritize those with the most significant implications.

4) **Foresight Workshop**
   The workshop applied a participatory foresight methodology to identify and prioritize emerging signals affecting carbon neutrality in APEC economies. Using horizon scanning, a Foresight Radar, and expert group discussions, participants classified signals as weak signals, strengthening trends, or wild cards, and collectively assessed their relevance and implications. This process enabled the selection of critical signals for policy reflection and strengthened regional foresight capacity to support adaptive and forward-looking climate strategies.

3 Key Challenges of APEC Economies on Climate Targets

The Asia-Pacific Economic Cooperation (APEC) region plays a pivotal role in global climate mitigation, given its significant share of global greenhouse gas (GHG) emissions. In 2022, APEC economies accounted for approximately 64% of global GHG emissions [1], while in 2023 they represented about 37% of the global population and 61% of global GDP [2]. As such, the region's pathway to carbon neutrality is a key determinant of global efforts to limit warming in line with the Paris Agreement.

Following the adoption of the Paris Agreement in 2015, most APEC economies have expressed long-term aspirations to move toward carbon neutrality around mid-century. By 2023, 19 out of 21 members had announced such goals—many targeting 2050, while a few are aiming for 2060. Within this group, Canada; Japan; the Republic of Korea; and New Zealand have already enacted legislation to anchor their 2050 commitments, while economies such as China; Indonesia; and Russia have outlined their ambitions for 2060 in economy strategies [3, 4].

At the same time, approaches remain diverse. Mexico continues to prioritize its 2030 emissions reduction objectives [5], and the Philippines has not yet set a mid-century timeline, reflecting current energy structures and development priorities [6]. This variation highlights both the progress already achieved and the opportunities for further dialogue and cooperation within APEC toward shared climate goals.

While political commitment to carbon neutrality is gaining momentum across APEC, translating these pledges into reality presents a complex set of challenges. APEC economies are highly diverse—ranging from the world's largest emitters to small developing economies —and thus confront both common and context-specific obstacles in their decarbonization pathways. This report provides a comprehensive review of the key challenges across multiple dimensions: *(1) policy and governance*, *(2) energy transition and technology*, *(3) finance and investment*, *(4) industrial and transport sector decarbonization*, *(5) social and just transition*, *and (6) data, measurement, reporting and verification (MRV), and capacity*. Each issue of challenges can be discussed as follows.

3.1 Policy and Governance Challenges

Robust and enforceable policy frameworks are foundational to achieving carbon neutrality across APEC economies. While nearly all members have announced carbon neutrality targets, translating these commitments into effective and sustained action remains uneven due to multiple governance-related constraints.

APEC economies face significant governance hurdles in turning net-zero (or carbon neutrality) pledges into concrete action. Only a few members, such as Canada and Japan, have legislated binding targets, while many others rely on aspirational plans that are vulnerable to political shifts, as seen in Australia and the USA [3]. Developing members often struggle with weak enforcement, limited authority, and fragmented institutions, which hinder coordination and alignment with Paris Agreement reporting requirements [7]. The voluntary nature of APEC also limits region-wide mechanisms like carbon pricing or efficiency standards, while local and regional governments may pursue divergent policies. Political economy pressures—particularly industry resistance and public sensitivity to energy costs—create further barriers, underscoring the need for social protection in climate policy [8]. In addition, several members' NDCs remain

misaligned with net-zero (or carbon neutrality) pathways, and few have independent oversight bodies, with New Zealand being a notable exception [3]. Finally, diverse governance systems add complexity: the USA faces political volatility, China must balance provincial consistency with growth, Southeast Asian economies face institutional gaps, and federal systems like Australia and Canada struggle with intergovernmental coordination [7].

While climate governance in APEC has progressed—especially in target-setting and regional dialogue—translating goals into consistent, enforceable, and inclusive economy action remains a major challenge. Strengthening legal frameworks, improving institutional coordination, and mainstreaming climate objectives across sectors will be essential for realizing carbon neutrality aspirations across the region.

3.2 Energy Transition and Technological Barriers

Transforming the energy systems of APEC economies is a central pillar of the region's pathway to carbon neutrality. While there has been commendable progress—such as being ahead of schedule in doubling renewable power share by 2030—fossil fuels remain dominant in the region's energy mix, reflecting deep-rooted structural and historical dependencies. APEC economies collectively hold over 70% of global coal reserves and substantial oil and gas resources, with coal, oil, and natural gas continuing to supply the majority of primary energy [1].

APEC economies face multiple barriers to achieving a clean energy transition. Renewable deployment remains too slow, with solar and wind needing to grow fourfold to meet net-zero (or carbon neutrality) pathways [9]. Integration is constrained by outdated grids, limited storage, and permitting delays, while regional power connectivity initiatives, such as the ASEAN Power Grid, are underutilized [10, 11]. Dependence on coal, oil, and gas infrastructure creates lock-in risks, and although strategies like ammonia co-firing are emerging, they are not yet widespread (Wogan, 2023). Promising technologies—including CCUS, green hydrogen, and advanced nuclear—remain costly and early-stage (Wogan, 2023). Supply chains for critical minerals such as lithium and cobalt are vulnerable, with China dominating processing, underscoring the need for diversification and circular economy approaches (Wogan, 2023). Domestic conditions, from land scarcity to hydropower reliance, further shape transition pathways. Ultimately, clear policy signals—such as carbon pricing, efficiency standards, and stronger regional cooperation—are essential to accelerate progress (Wogan, 2023).

While APEC economies have strong innovation potential and have launched major public investment programs - such as the USA Inflation Reduction Act and Japan's Green Transformation bonds [9] - accelerating the energy transition will require enhanced infrastructure, regional cooperation, and consistent policy signals, including carbon pricing and technology standards. With sustained effort, the region can play a leadership role in delivering a secure, just, and inclusive energy transformation.

3.3 Financial and Investment Gaps

Achieving carbon neutrality across APEC economies will depend heavily on the ability to mobilize and allocate financial resources at an unprecedented scale. Despite increasing commitments, significant investment shortfalls, institutional limitations, and market inefficiencies persist.

Bridging the climate finance gap in APEC requires addressing both scale and structural barriers. Current flows (≈USD 850 billion annually) fall far short of the USD 7.3 trillion needed each year to reach net-zero by 2050 [12, 13]. Financing gaps are most severe in developing economies, particularly in Southeast Asia and the Pacific, where debt burdens, fossil fuel subsidies, and limited fiscal space constrain investment needs estimated at over USD 210 billion by 2050 [14]. Public finance is inadequate, and private capital remains underleveraged due to policy uncertainty, credit risks, and underdeveloped instruments [13]. International climate finance is fragmented, with uneven access for adaptation and smaller economies, despite initiatives like Indonesia's USD 20 billion Just Energy Transition Partnership [3]. Advanced members such as Canada; Japan; and Singapore are beginning to adopt stress tests and taxonomies, but broader financial preparedness is needed. Investments also remain concentrated in energy, leaving industry, transport, agriculture, and adaptation underfunded [13]. Persistent fossil subsidies, varied economy strategies, and inconsistent data and MRV systems undermine progress, while innovative tools such as green bonds, transition finance, and carbon markets remain underutilized [3]. Ensuring inclusivity—by supporting SMEs, women-led businesses, and Indigenous communities—and strengthening capacity-building and regional cooperation will be vital to mobilize finance at the necessary scale [7].

Mobilizing climate finance at the necessary scale across APEC will require a holistic and coordinated approach—combining strong domestic policies, regional platforms, and international support. Closing the climate finance gap is not only a technical challenge, but a strategic imperative to achieve inclusive, sustainable, and resilient growth across the Asia-Pacific region.

3.4 Sectoral Decarbonization

Achieving economy-wide carbon neutrality will require deep emissions reductions in **all sectors**, but particularly in the traditionally hard-to-abate sectors of industry and transport. These sectors pose distinctive challenges across APEC economies, given their scale, technological requirements, and entrenched infrastructure.

- **Industrial Decarbonization Challenges**

Decarbonizing the industrial sector is a critical component of APEC's carbon neutrality strategy, given its substantial share of energy use and CO_2 emissions. The complexity and emissions-intensity of many industrial processes present unique challenges that require long-term, coordinated solutions.

Decarbonizing industry in APEC is complex due to both technological and structural barriers. Many emissions come from intrinsic process reactions in cement and

steelmaking, which electrification alone cannot solve [10]. Low-carbon options such as green hydrogen, high-temperature electrification, and CCUS remain costly, early-stage, and limited in deployment. Retrofitting or retiring carbon-intensive industrial assets in major economies like China; Japan; Korea; Russia; and the USA entails high costs and competitiveness risks. Rapid industrialization in developing members such as Indonesia; Mexico; and Viet Nam risks locking in fossil-based growth unless early interventions are made. While advanced economies are piloting innovations such as ultra-low emission steel and hydrogen metallurgy, scalability remains uncertain. Near-term opportunities exist in electrifying low- and medium-temperature processes, though high-temperature applications remain challenging. Effective policy frameworks—including carbon pricing, emissions trading, and industry-government partnerships—are needed to balance ambition with competitiveness. Given the diversity of industrial contexts across the region, tailored strategies are essential, from managing extractive sectors in Australia and Canada to supporting SMEs in Southeast Asia with finance and technical assistance. Decarbonizing the industrial sector across APEC will require a multidimensional strategy—one that promotes breakthrough technology deployment, supportive and flexible policy design, targeted finance, and regional cooperation. Addressing disparities in technological and institutional capacity—particularly for SMEs and developing members—will be vital to ensuring an equitable and effective transition aligned with APEC's net-zero objectives.

- **Transport Decarbonization Challenges**

The transport sector accounts for nearly one-fifth of energy-related CO_2 emissions in both APEC and globally, making it a central focus of decarbonization efforts (APEC, 2023) [50]. Reducing emissions in this sector is inherently complex due to vast and growing vehicle fleets, long infrastructure lifespans, and deeply embedded mobility and trade systems. APEC economies must pursue a mix of technological, behavioral, and policy solutions tailored to diverse domestic contexts and transport modes.

Transport is a major source of emissions in APEC, with road transport dominating and EV adoption uneven. China leads with EVs accounting for over 20% of new vehicle sales in 2023, while uptake in Southeast Asia and Latin America remains constrained by high costs, limited charging infrastructure, and consumer hesitancy [15]. Charging networks and EV supply chains are developing but face bottlenecks, alongside rising demand for critical minerals such as lithium, cobalt, and nickel. While electrification is the long-term goal, interim strategies include improving fuel economy, promoting biofuels, and expanding mass transit and non-motorized mobility, though these require integrated urban planning and major investment. Aviation and shipping—both hard-to- abate sectors—depend on scaling sustainable aviation fuels (SAF), port electrification, vessel efficiency upgrades, and green shipping corridor initiatives [15, 16, 17]. Systemic and behavioral challenges—such as consumer preferences, freight logistics, and car- centric urban forms—may hinder progress without enabling policies like EV incentives, efficiency standards, and land-use reforms. Decarbonization pathways differ across the region: North America and Oceania face entrenched car dependence, East Asia must address aviation and maritime emissions, Southeast Asia and Latin America are at a pivotal stage of transport growth, and Chile demonstrates leadership with its electric bus deployment.

Decarbonizing APEC's transport sector will require a comprehensive strategy integrating **technological innovation** (EVs, SAF, zero-emission shipping), **enabling policies** (incentives, standards, infrastructure), and **behavioral change**. Regional cooperation—particularly in sharing best practices, aligning standards, and supporting infrastructure development—can significantly accelerate the shift toward a low-carbon, inclusive, and resilient transport system across the Asia-Pacific.

3.5 Social and Just Transition Considerations

Achieving carbon neutrality across APEC economies is not only a technological and economic undertaking but also a deeply social process. A just transition—one that prioritizes fairness, inclusion, and equity—is essential to securing public trust, maintaining social stability, and ensuring no one is left behind in the shift toward a low-carbon future.

Achieving carbon neutrality in APEC requires addressing major social dimensions to ensure fairness and inclusion. Many jobs remain tied to fossil fuel industries, creating risks of displacement and regional disruption; while global employment gains are expected, transitions will be uneven and require proactive measures such as reskilling, social protection, and economic diversification [8]. Vulnerable groups—including rural communities, informal workers, and Indigenous populations—are especially at risk, making equity safeguards and stakeholder engagement essential. Economies such as Canada; Chile; New Zealand; and Peru highlight the importance of integrating Indigenous rights and traditional knowledge into climate strategies [17]. Energy affordability also poses challenges, as carbon pricing or subsidy reforms may increase energy poverty unless paired with compensatory mechanisms; examples include Canada's household dividends and targeted rural electrification programs in developing economies [3]. Building public awareness and societal support is equally critical, requiring transparency and participatory approaches like citizens' assemblies to sustain legitimacy [8]. Finally, institutional readiness varies: high-income members often have stronger capacity, while developing economies must balance climate goals with poverty reduction and job creation. Positive practices—such as New Zealand's Just Transition Unit and the USA Justice40 Initiative—illustrate pathways for embedding social equity, though others, like Russia, require further efforts.

A just transition is not only a moral imperative—it is also essential for the success of APEC's climate goals. Ensuring fairness in the distribution of costs and benefits, protecting vulnerable communities, and promoting inclusive economic opportunities will strengthen the resilience and legitimacy of the low-carbon transition. Through platforms such as APEC and partnerships under the UN Climate Action Empowerment agenda, member economies can exchange best practices, strengthen institutional capacity, and jointly advance a transition that is socially inclusive, economically viable, and environmentally sustainable.

3.6 Data, MRV, and Capacity Constraints

Robust data systems and institutional capacity are essential for effective climate policy planning, implementation, and accountability. In the APEC region, where member

economies face diverse institutional and technical contexts, the establishment of high-quality measurement, reporting, and verification (MRV) systems is a foundational requirement for tracking progress toward carbon neutrality and meeting commitments under the Paris Agreement.

Robust data and monitoring systems are critical for achieving carbon neutrality, but many APEC members face persistent gaps. Developing economies often lack complete sectoral data, rely heavily on default emission factors, and struggle with fragmented reporting and weak coordination among ministries [7]. Human resource shortages are a major bottleneck— some economies like Papua New Guinea or Peru depend on very limited staff, making systems fragile despite support from partners such as GIZ, UNFCCC, and APEC [7]. Tracking of mitigation outcomes remains limited, with few economies having frameworks to measure avoided emissions, which in turn restricts access to climate finance [13]. Verification and quality assurance protocols are often weak or inconsistent, and advanced MRV technologies like satellite monitoring remain inaccessible to many low-capacity members [7]. NDC tracking capacity also varies: some members (e.g., China; the Philippines) have in-house models, while others depend on external consultants, limiting long-term institutional development [7]. Progress is uneven, with developed economies like Australia; Japan; and the USA maintaining advanced systems, while smaller Pacific members are only at initial stages. Local and regional data, along with private-sector inputs, remain poorly integrated, raising risks of duplication and gaps as carbon markets expand. Nonetheless, good practices are emerging—such as Korea's GHG management system linked to its ETS and Mexico's mitigation tracking tool aligned with domestic law—highlighting the potential of centralized data units and inter-agency sharing to strengthen regional transparency [7]. High-quality data and institutional capacity are critical to the success of APEC's carbon neutrality commitments. Transparent MRV systems underpin effective policy, attract climate finance, and enable participation in international mechanisms such as Article 6 carbon markets. Strengthening domestic capacities—in terms of personnel, institutions, and technology—alongside fostering regional knowledge-sharing, will be key to building trust, guiding investment, and ensuring sustained progress toward climate goals across APEC.

4 List of Emerging Signals and Implications

4.1 Identification of Emerging Signals

4.1.1 Thematic of Emerging Signals

To better capture the dynamics of change, emerging signals identified in the literature review and horizon scanning have been reorganized into three thematic clusters. This thematic balance provides a forward-looking lens to understand how signals may either accelerate or constrain carbon neutrality across APEC economies. The clusters are:

(1) Technology-driven Transition

This cluster reflects signals on the supply side of decarbonization, where innovation in energy systems and disruptive technologies redefine the landscape. Signals include:

- **Renewable integration through smart grids, regional grid codes, and microgrids**, enabling greater resilience and flexibility.
- **Electromobility momentum**, with EV mandates, ecosystem investments, and complementary battery reuse, recycling, and second-life applications.
- **Diversification into next-generation fuels and storage**, including hydrogen and ammonia economies, CO_2 batteries, algae power, and renewable energy liquids.
- **Shifts in business and consumer models**, demonstrated by corporate PPAs and the rise of energy prosumerism.
- **Critical minerals diplomacy and strategic stockpiling**, highlighting resource security as a geopolitical dimension of the clean energy transition.
- **Disruptive breakthroughs**, such as AI for decarbonisation, the EV battery and graphene revolutions, small modular reactors, thorium power, CCUS-as-a-service, and zero-emission data centers.

These signals collectively illustrate rapid diversification of technological pathways, while also introducing new vulnerabilities such as grid outage risks and mineral dependency.

(2) Nature and society resilience

This cluster integrates ecosystems and equity, emphasizing resilience and inclusivity in the low-carbon transition. Signals include:

- **Ecosystem-based mitigation**, such as aquaculture linked to blue carbon credits, regenerative and carbon farming, and renewed focus on oceans as carbon sinks.
- **Escalating environmental risks**, including food insecurity, endangered crops, global water shortages, and potential resource conflicts.
- **Social equity dimensions**, including large-scale worker reskilling and transition programs, the rise of Generation Z climate perspectives, and hybridisation of society in response to systemic shocks.
- **Climate–health nexus**, where the spread of climate-induced diseases underscores the intersection of environmental stressors and public health.

These signals highlight the need for carbon neutrality strategies that not only cut emissions but also safeguard biodiversity, food–water security, and social stability.

(3) Enabling Frameworks

This cluster addresses the financial and institutional enablers that underpin successful transitions. Signals include:

- **Strengthening governance**, with legal enforcement of net-zero targets, long-term climate action plans, and enhanced cooperation platforms such as upgraded APEC mechanisms, ASEAN Power Grid initiatives, and alignment with frameworks like the EU Taxonomy.

- **Expanding policy instruments**, including carbon trading systems, environmental and Pigouvian taxes, and border carbon adjustments, balanced against political sensitivities around energy pricing.
- **Financial diversification**, with climate risk guarantees, transition bonds, and nature-based bond frameworks attracting new investors, though anti-carbon tax movements reveal persistent societal resistance.
- **MRV innovation**, including integrated MRV–data platforms that link inventories with policy outcomes, and regional climate data governance platforms that improve transparency and comparability.
- **Capacity building**, exemplified by peer learning and twinning programs between advanced and emerging members.

Together, these signals reveal that governance, finance, and measurement are indispensable for scaling climate action. Yet political economy dynamics remain decisive in shaping the pace and inclusivity of implementation.

In summary**,** reframing the emerging signals into these three thematic clusters provides a more balanced foresight perspective:

- *Technology-driven transition* (supply-side innovation),
- *Nature & society resilience* (people–ecosystem balance), and
- *Enabling frameworks* (money, regulation, measurement).

This structure not only helps policymakers track weak signals across multiple domains but also supports APEC economies in developing adaptive strategies that integrate technology, environment, society, and institutional enablers in a coherent pathway toward carbon neutrality.

4.1.2 Emerging Signals in Relation to APEC's Carbon Neutrality Challenges

The literature review of APEC economies demonstrates that the pursuit of carbon neutrality is shaped by a set of persistent structural challenges. These include the absence of binding and coherent policy frameworks, slow progress in energy transition due to fossil fuel lock-in and technological barriers, insufficient mobilization of climate finance, difficulties in decarbonizing industrial and transport sectors, social and equity concerns associated with just transition, and gaps in data systems and MRV capacity. Collectively, these challenges illustrate the complex governance, economic, and social dynamics that constrain the realization of net-zero (or carbon neutrality) commitments across the region.

Within this context, the identification of **emerging signals** provides an important forward-looking lens. Signals represent early indicators of change—technological, institutional, financial, or societal—that may interact with or reshape existing barriers. Some signals hold the potential to mitigate structural constraints, for example by enabling new business models or enhancing institutional capacities, while others may introduce additional risks or uncertainties. By systematically linking signals to the challenge areas identified in the literature, this analysis provides a structured foundation for anticipating transformative pathways, informing policy responses, and guiding regional cooperation toward carbon neutrality in APEC.

(1) Policy and Governance

This area refers to the legal, institutional, and political frameworks that guide climate action. Emerging signals suggest a gradual strengthening of governance. Several economies are introducing **legal enforcement mechanisms for net-zero targets** and adopting **long-term climate action plans with legal backing** to ensure continuity. At the regional level, proposals for **enhanced APEC climate cooperation** and the **ASEAN Power Grid** reflect increasing political priority for cross-border initiatives. Nevertheless, **energy pricing remains a politically sensitive trigger**, and the rise of **border carbon adjustments** signals potential trade friction. Initiatives for **regional climate data governance platforms** and alignment with international frameworks such as the **EU Taxonomy** further indicate a trend toward harmonization and institutionalization.

(2) Energy Transition and Technology

This area concerns the transformation of energy systems away from fossil fuel dependency, supported by innovation and infrastructure. Signals reveal an expanding range of solutions: corporations are securing **renewable energy through power purchase agreements (PPAs)**, while governments are scaling **smart grids** and adopting **regional grid codes** to improve electricity integration. Circular economy practices are evident in **battery reuse, recycling, and second-life applications**, reducing reliance on critical minerals. Meanwhile, **EV mandates and ecosystem investments** show policy- driven momentum in mobility, complemented by **mineral diplomacy and stockpiling strategies**. Emerging alternatives such as the **hydrogen and ammonia economies**, **CO_2 batteries**, **algae power**, and **renewable energy liquids** reflect experimentation with next-generation fuels. Decentralized models like **microgrids** and **energy prosumerism** also highlight diversification, though risks such as **large-scale grid outages** remain salient.

(3) Environment and Natural Resources

This area highlights how ecosystems and natural resources serve as both constraints and opportunities. Emerging signals such as **aquaculture linked to blue carbon credits** underscore the integration of marine systems with carbon markets. In contrast, negative signals—such as **food insecurity, endangered crops, and the global water crisis**—illustrate growing vulnerabilities. Rising competition may escalate into **resource conflicts**, adding a geopolitical dimension. At the same time, practices like **carbon farming and regenerative agriculture** are reframing land use as a carbon sink, and renewed attention to the **ocean's role as a carbon absorber** points to potential large-scale natural solutions.

(4) Finance

Finance represents a decisive enabler of decarbonization. Signals indicate diversification in instruments and strategies. **Climate risk guarantees** are being piloted to mobilize private capital, while **transition bonds** target emission reductions in high-carbon sectors. **Nature-based bond frameworks** are attracting investors focused on biodiversity. At the same time, conventional mechanisms such as **carbon trading and environmental taxes** remain important, though **anti-carbon tax movements** highlight the political sensitivity of fiscal reforms. Collectively, these signals reveal a trend toward financial innovation, but also persistent risks of uneven access and societal resistance.

(5) Social and Just Transition

This area emphasizes fairness and inclusivity in the low-carbon shift. Emerging signals point to expanded **worker reskilling and transition programs** to support those employed in fossil-based sectors. The perspectives of **Generation Z** are reshaping expectations, as younger cohorts entering the workforce prioritize sustainability and climate action. Broader societal shifts are captured in the notion of **hybridisation of society**, while the spread of **climate change-induced diseases** underscores the link between health and climate resilience. These signals highlight that addressing social justice, employment, and health will be critical to sustaining public legitimacy in the transition.

(6) Data, MRV, and Capacity

This area refers to the systems and skills necessary for **measurement, reporting, and verification (MRV)** of emissions and mitigation outcomes. Emerging signals highlight innovation in capacity building. **Integrated MRV-data platforms** are linking inventories with policy outcome tracking, enhancing transparency and accountability. **Peer learning and twinning programs** are pairing advanced and developing APEC members, facilitating mutual capacity building and knowledge exchange. These developments suggest a move toward more harmonized and cooperative approaches, though institutional fragility remains a barrier in smaller economies.

(7) Technology and Innovation

This area captures disruptive breakthroughs that can accelerate decarbonization. Signals include **AI for decarbonisation, Green AI, and zero-emission data centres**, which combine digital transformation with emissions reduction. Agriculture and food are being reshaped by **animal-free dairy, lab-grown foods, and precision or regenerative agriculture**, offering pathways to reduce land-use emissions. Advances such as the **EV battery revolution and graphene revolution** suggest future leaps in storage and materials science. On the energy side, **small modular nuclear reactors and thorium power plants** present new clean baseload options, while **mega-infrastructure for adaptation** reflects the scale of resilience challenges. In carbon management, the development of **CO_2 transport and storage infrastructure** and the emergence of **CCUS-as-a-service** signal innovative pathways to deploy carbon capture at scale without prohibitive costs for individual firms.

Table 1 List of Emerging Signals in Relation to APEC's Carbon Neutrality Challenges

Challenge Area	Signal	Explanation
Data & MRV	Integrated MRV-data platforms	Economies are linking emissions inventories with policy outcome tracking systems.
Data & MRV	Peer learning and twinning programs	Capacity-building initiatives pair advanced and emerging APEC members for mutual training.
Energy Transition and Technology	Corporate PPAs for clean power	Corporations are signing long-term contracts for renewable energy to meet sustainability goals.

Challenge Area	Signal	Explanation
Energy Transition and Technology	Smart grid scale-up programs	Smart grid technologies are scaling up to manage renewable energy fluctuations.
Energy Transition and Technology	Development of regional grid codes	Standardized grid codes are enabling transboundary electricity trading.
Energy Transition and Technology	Battery reuse and second-life initiatives	Reuse of EV and stationary batteries is gaining traction for distributed energy storage.
Energy Transition and Technology	Hydrogen diplomacy	Bilateral agreements are shaping global green hydrogen trade routes.
Energy Transition and Technology	EV adoption mandates	Mandates for EV sales shares or ICE phase-out dates are being legislated in several economies.
Energy Transition and Technology	Battery recycling and circular economy	Increasing focus on end-of-life battery processing and recovery of rare metals.
Energy Transition and Technology	Microgrids	Small-scale electricity distribution networks operating independently or with main grid
Energy Transition and Technology	Energy Prosumerism	Consumers who produce part of their electricity needs and inject surplus into grid
Energy Transition and Technology	Massive Grid and Network Outage	Large-scale malfunction shutting down electric grids and data networks
Energy Transition and Technology	Hydrogen Economy	Economic system where hydrogen replaces liquid fuels and serves as primary energy storage
Energy Transition and Technology	CO2 Battery	Rechargeable battery using carbon dioxide as cathode for energy storage
Energy Transition and Technology	Algae Power	Energy production utilizing algae in bioreactors for sustainable power generation
Energy Transition and Technology	Ammonia Economy	Economic system using synthetic green ammonia as carbon-free energy source
Energy Transition and Technology	Renewable Energy Liquid	Liquid carriers for storing renewable energy over long periods
Environment and Natural Resources	Aquaculture and Blue Carbon Credits	Marine farming combined with ocean carbon sequestration credits
Environment and Natural Resources	Food Insecurity	Growing mismatch between food demand and production/distribution capacity
Environment and Natural Resources	Endangered Foods	Crops and food varieties facing extinction due to climate change and biodiversity loss
Environment and Natural Resources	Resource Wars	Intensified struggles for control of scarce natural resources

Challenge Area	Signal	Explanation
Environment and Natural Resources	Global Water Crisis	Potential 40% shortfall in fresh water supply vs demand by 2030
Environment and Natural Resources	Regenerative Farming	Agricultural practices transforming farms from carbon emitters to carbon sinks
Environment and Natural Resources	Ocean as a Strong Carbon Sink	Enhanced understanding and utilization of oceans' carbon absorption capacity
Finance	Climate risk guarantees	Guarantees are being tested to crowd in private investment into clean energy and resilience.
Finance	Transition bonds for high-carbon sectors	Used to finance emission-reduction efforts in industries like steel, cement, and fossil transition.
Finance	Nature-based bond frameworks	Green bonds tied to forest, land, and biodiversity protection are gaining investor interest.
Finance	Anti-carbon tax movements	Fuel tax reforms have triggered public backlash in multiple APEC members.
Finance	Carbon Trading and Carbon Credit	Market mechanisms for trading carbon emissions allowances and offsets
Finance	Environmental & Pigouvian Taxes	Taxes designed to discourage environmentally harmful activities
Policy and Governance	Legal mechanisms for net-zero enforcement	Governments are institutionalizing legal accountability mechanisms to ensure policy continuity.
Policy and Governance	Long-term climate action plans with legal backing	Climate action plans increasingly include multi-decade timelines and legal backing.
Policy and Governance	Upgraded APEC climate mechanisms/APEC cross-ministerial on climate change	APEC is considering stronger cooperation platforms for technology and finance alignment.
Policy and Governance	Accelerated ASEAN Power Grid deployment	Grid interconnection is progressing slowly but gaining policy priority.
Policy and Governance	Energy pricing as political trigger	Energy affordability remains a politically sensitive issue in transitions.
Policy and Governance	Border carbon adjustments	Carbon import tariffs are being discussed to level the playing field on trade emissions.
Policy and Governance	Regional climate data governance platforms	New initiatives aim to harmonize MRV and emissions tracking across APEC economies.

Challenge Area	Signal	Explanation
Policy and Governance	EU Taxonomy for Sustainable Activities	Classification system defining environmentally sustainable economic activities
Social and Just Transition	Worker reskilling and transition programs	Job training and relocation support is being scaled for fossil-sector workers.
Social and Just Transition	Generation Z Climate Perspectives	Digital-native generation entering job markets with different climate perspectives
Social and Just Transition	Hybridisation of Society	Dynamic, adaptable and multidimensional transformation of social structures
Social and Just Transition	Climate Change-Induced Diseases	Spread of infectious diseases due to changing temperature and precipitation patterns
Technology and Innovation	Animal-Free Dairy Products	Synthetic biology creating dairy products without using animals
Technology and Innovation	Artificial Meat	Synthetic products mimicking meat to reduce environmental impact
Technology and Innovation	Lab-Grown Foods	Food and beverage ingredients grown from animal and plant cells in laboratories
Technology and Innovation	Precision & Robotic Agriculture	Large-scale robotization and digitalization of farming operations
Technology and Innovation	Regenerative Agriculture	Holistic farming approach balancing ecological sustainability
Technology and Innovation	EV Battery Revolution	Development of alternatives to lithium-ion batteries for electric vehicles
Technology and Innovation	Graphene Revolution	Advanced material superior to current known materials in multiple properties
Technology and Innovation	Zero-Emission Data Centers	Data centers operating with renewable energy and carbon capture technology
Technology and Innovation	Green AI	The development and use of artificial intelligence in ways that minimize environmental impact—focusing on reducing the energy and carbon footprint of AI systems
Technology and Innovation	Small Nuclear Power Plants	Safe, transportable small modular reactors for clean energy generation
Technology and Innovation	Thorium Power Plants	Nuclear power using thorium as alternative to traditional uranium
Technology and Innovation	Mega-Infrastructure for Climate Adaptation	Large-scale infrastructure projects for human adaptation to climate change

Challenge Area	Signal	Explanation
Technology and Innovation	CO2 transport and storage infrastructure	Dedicated CO2 pipelines and offshore storage sites are being developed to enable CCUS deployment.
Technology and Innovation	CCUS-as-a-service	A model where specialized providers handle the capture, transport, and storage of CO_2 for emitters, offering scalable carbon management without high upfront costs

4.2 Survey on Emerging Signals for Carbon Neutrality

As part of the foresight-oriented methodology, an online survey was conducted to validate and prioritize emerging signals that may affect APEC economies' pathways toward carbon neutrality. The survey served as a key mechanism to integrate expert perspectives across the region, ensuring that the signals identified through literature review and horizon scanning reflected both technical insights and the diverse contexts of member economies.

The survey was designed to collect feedback from experts in government agencies, academia, research institutions, and the private sector. Questions focused on assessing the **relevance, potential impact, and urgency** of emerging signals in science, technology, and innovation, as well as in governance, finance, and social transition. Respondents were asked to evaluate signals across multiple thematic areas, including energy and technology innovation, environment and resources, social and just transition, and enabling frameworks such as finance, policy, and MRV systems.

To facilitate participation, the survey was structured for completion in approximately 15 minutes and allowed respondents to save progress and return at their convenience. The survey was open until 22 September 2025, providing adequate time for experts across APEC economies to contribute their perspectives.

The responses generated through this process provide valuable evidence base for identifying which signals warrant closer monitoring and policy attention. By capturing expert judgments from across the region, the survey strengthens the foresight capacity of APEC economies and supports the development of policy recommendations that are more adaptive, inclusive, and responsive to emerging risks and opportunities.

4.2.1 Survey Content Design and Respondents

The survey was designed to validate and prioritize emerging signals that may affect APEC economies' pathways toward carbon neutrality. It was structured around seven challenge areas identified through literature review and horizon scanning (see topic 4.1):

1) **Energy Transition and Technology** – signals related to renewable energy, smart grids, hydrogen, EVs, storage, and grid resilience.
2) **Environment and Natural Resources** – signals linked to biodiversity, food, water, and resource security.

3) **Finance** – financial instruments and barriers, including carbon trading, green bonds, and public resistance to carbon taxes.
4) **Policy and Governance** – signals covering regulatory frameworks, enforcement mechanisms, and regional cooperation platforms.
5) **Social and Just Transition** – signals addressing workforce reskilling, generational perspectives, equity, and health impacts.
6) **Data & MRV** – signals on measurement, reporting, and verification (MRV) systems, including integrated platforms and peer learning.
7) **Technology and Innovation** – disruptive innovations such as AI, lab-grown food, graphene, small modular nuclear reactors, and CCUS-as-a-service.

For each signal, respondents were asked to assess three dimensions:

- **Impact** – how significant the signal could be for carbon neutrality
- **Likelihood** – the probability of the signal materializing within their context
- **Urgency** – the degree to which the signal requires attention in their economy.

This structure ensured that the survey captured both expert judgment and contextual perspectives on the relevance of different signals. The combination of thematic areas and quantitative ratings provided a systematic approach to identify which signals are most critical, where they may emerge first, and how urgently policymakers should respond.

The overall profile of survey respondents is illustrated in Figure 1 and Figure 2. Responses were received from five APEC economies— Brunei Darussalam; Indonesia; Peru; Chinese Taipei; and Thailand— demonstrating cross-economy participation. The respondents represented a diverse range of organizations, with government agencies and educational institutions accounting for the largest shares, complemented by contributions from the private sector, NGOs, non-profit associations, and APEC-affiliated research institutes. In terms of expertise, the majority of participants reported more than ten years of experience in climate change–related fields, while smaller groups indicated mid-level or early-stage experience. Taken together, these results show that the survey engaged a broad and diverse set of stakeholders, ensuring that the insights gathered are both credible and grounded in substantial professional experience.

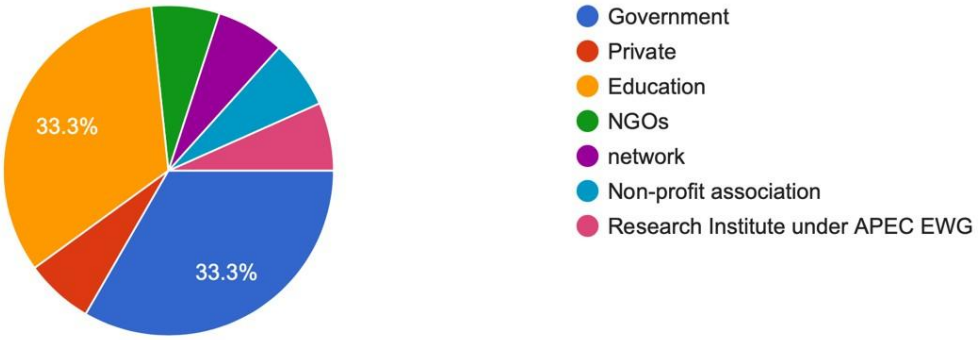

Figure 1 Type of organization

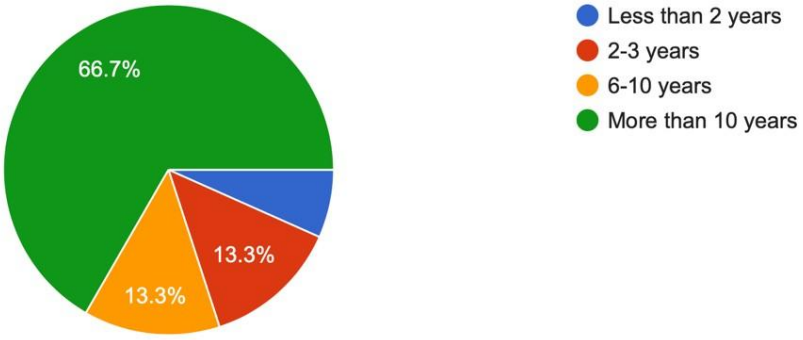

Figure 2 Expert's experience relevant to climate change

4.2.2 Survey Results on Emerging Signals

The survey generated valuable insights into how experts across APEC economies perceive the significance of emerging signals affecting pathways toward carbon neutrality. Respondents evaluated each signal in terms of *impact, likelihood, and urgency*, providing structured evidence base for foresight-informed policy recommendations.

To interpret the survey findings systematically, the average scores of impacts, likelihood, and urgency for each emerging signal were categorized into five levels: Low (<1), Medium-Low (1–2), Medium (2–3), Medium-High (3–4), and High (>4). This framework provides a transparent method for distinguishing between weak signals that require basic monitoring, medium-range signals that may evolve into important drivers, and high-scoring signals that demand immediate policy action. The distribution of these scores is illustrated in Figure 3 (Heatmap of Impact, Likelihood, and Urgency), which provides a clear comparative overview of all signals.

1) **Overall Trends**

Across the seven challenge areas, several clear patterns emerged:

- **High-impact and high-likelihood signals** were concentrated in the domains of **energy transition, governance, and environmental security**, indicating that transformative drivers are already visible in the near term.
- **Urgency ratings** were especially high for signals linked to **EV adoption, smart grids, food and water security, and worker reskilling**, underscoring areas where immediate action is required to prevent lock-in or social disruption.
- A set of **uncertain but potentially transformative signals**—such as thorium power, graphene materials, CCUS-as-a-service, and lab-grown food—received medium to medium-high scores, suggesting the need for strategic preparedness rather than immediate deployment.
- Social and political dynamics, including **anti-carbon tax movements and energy pricing sensitivity**, scored as medium-to-high in likelihood and urgency, highlighting political economy risks that could undermine decarbonization if not proactively managed.

2) **Cluster Highlights**

- **Energy Transition & Technology**: Signals such as *EV adoption mandates* and *smart grid scale-up* received some of the highest ratings across all dimensions, pointing to their critical role in accelerating decarbonization. Meanwhile, frontier options like *hydrogen economy* and *ammonia fuel* were rated medium-high,

indicating recognition of their importance but with some uncertainty on pace of adoption.

- **Environment & Natural Resources**: *Food insecurity* and *global water crisis* were consistently rated high in both impact and urgency, making them priority issues that link climate policy with human security. Conversely, signals like *endangered foods* and *resource wars* were rated as important but less urgent, warranting ongoing monitoring.
- **Finance**: *Carbon trading* and *nature-based bonds* scored medium-to-high across all three metrics, signaling growing relevance of market-based mechanisms. At the same time, *anti-carbon tax movements* were identified as urgent socio- political risks despite lower systemic impact.
- **Policy & Governance**: Signals tied to legal mechanisms for net-zero enforcement **and** long-term climate action plans scored highly, reflecting expert consensus that stronger institutional frameworks are essential. Regional-level signals, including *ASEAN Power Grid* and *border carbon adjustments*, were viewed as medium-high, indicating opportunities for cross-economy cooperation.
- **Social & Just Transition**: *Worker reskilling programs* stood out with high urgency, underlining the importance of addressing labor market disruptions from decarbonization. *Generation Z perspectives* and *climate-induced diseases* were rated medium, highlighting emerging but less immediate drivers.
- **Technology & Innovation**: Disruptive technologies such as *EV battery revolution*, *graphene*, and *AI for decarbonisation* received medium-to-high scores, while options like *thorium power* and *lab-grown food* remained in the watchlist category—important to monitor but not yet decisive for policy.
- **Data & MRV**: *Integrated MRV-data platforms* and *peer learning initiatives* scored high across all dimensions, signaling strong consensus that robust and transparent data systems are critical enablers for effective carbon neutrality pathways.

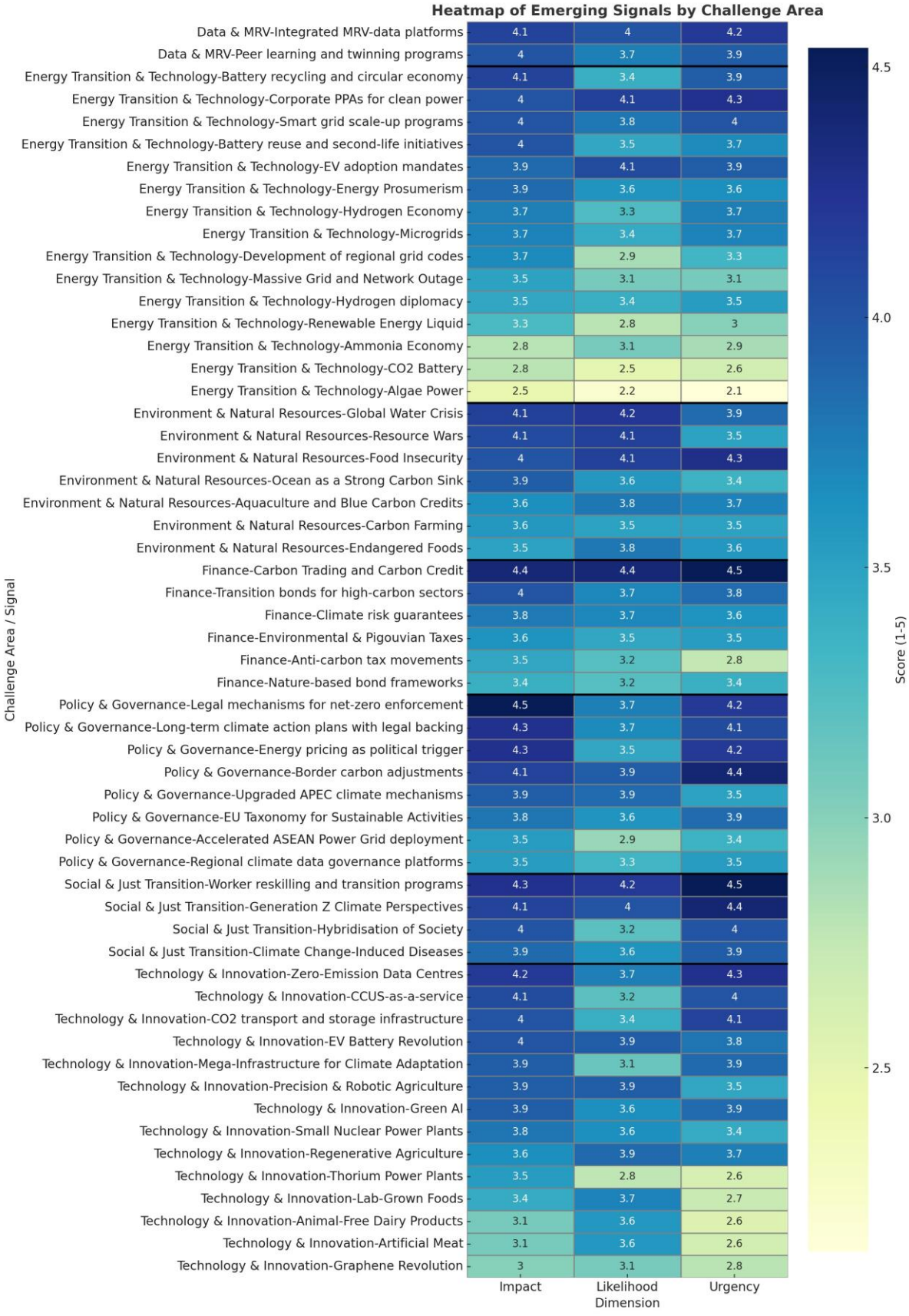

Figure 3 Heatmap of Impact, Likelihood, and Urgency

4.3 Ranking of Signals

The survey results provide more than just a technical ranking of signals; they create structured evidence base for policy prioritization within APEC economies. By combining assessments of *impact*, *likelihood*, and *urgency*, the survey offers a foresight lens that helps policymakers distinguish between signals that are transformative but long-term, versus those that are both imminent and pressing.

To translate foresight findings into actionable guidance for policymakers, the survey results were analyzed using a Policy Matrix framework, as shown in Table 2. This framework links the dimensions of impact, likelihood, and urgency with tailored policy response types. By categorizing signals into five score ranges—Low (<1), Medium-Low (1–2), Medium (2–3), Medium-High (3–4), and High (>4)—the matrix enables policymakers to differentiate between critical priorities requiring immediate intervention, signals suited for long-term planning, risks that demand mitigation, and weak signals that should be placed on a monitoring list. In addition, cross-border signals are highlighted as requiring regional cooperation mechanisms.

Table 2 Policy Matrix framework

Impact	Likelihood	Urgency	Policy Response Type	Interpretation
High (>4)	**High** (>4)	**High** (>4)	**Immediate Policy Action**	Critical signals – require urgent policy measures, funding, and international cooperation.
High (>4)	**Medium-High (3-4)**	**Medium-High to High (≥3)**	**Planned Deployment**	Emerging but credible signals – integrate into mid-term economy strategies.
Medium-High (3-4)	**High (>4)**	**High (>4)**	**Risk Mitigation**	Signals with political economy or social disruption risks – need policy safeguards.
Medium (2-3)	**Medium-High (3-4)**	**High (>4)**	**Strategic Preparedness**	Weak but urgent signals – monitor closely, prepare pilot programs or R&D.
Medium-Low (1-2)	Any	Any	**Watchlist / Monitoring**	Currently weak signals – track developments, no immediate intervention.
Cross-border (any with high regional relevance)	Variable	Variable	**Regional Cooperation Priority**	Signals that require harmonized standards, joint investment, or shared data/MRV platforms.

By applying the Policy Matrix framework, signals can be clustered into six main response types (as shown in Table 3):

- **Immediate Policy Action**

Signals that scored High (>4) across all three dimensions are classified as urgent priorities for rapid intervention. These include EV adoption mandates, smart grid scale-up, food insecurity, global water crisis, and integrated MRV-data platforms. Their consistent ratings confirm that these drivers are already shaping carbon neutrality pathways in the region. The policy implication is clear: APEC economies must mobilize funding, establish enabling regulations, and coordinate regionally to accelerate deployment and prevent carbon lock-in.

- **Planned Deployment**

Signals with High impact but only *Medium-High (3–4)* likelihood or urgency, such as the hydrogen economy, carbon farming, battery recycling, and nature-based bond frameworks, represent credible but evolving opportunities. They may not require urgent intervention but should be integrated into mid- to long-term economy strategies. Policies should emphasize capacity building, incentives for investment, and pilot scaling to ensure these opportunities mature into reliable decarbonization pathways.

- **Risk Mitigation**

Certain signals scored Medium-High (3–4) in impact but very high in likelihood and urgency, particularly those tied to social and political dynamics. Examples include anti-carbon tax movements and energy pricing as a political trigger. These are not primarily technological or environmental challenges, but political economy risks that could undermine policy progress. Addressing them requires proactive safeguards, including transparent communication, inclusive stakeholder engagement, and compensatory measures to maintain public trust and policy continuity.

- **Strategic Preparedness**

Signals in the Medium (2–3) impact range but rated high in urgency—such as thorium power plants, CCUS-as-a-service, and lab-grown foods—are uncertain but potentially transformative technologies. While their near-term deployment is not feasible, they represent possible game changers. Policymakers should therefore invest in R&D, demonstration projects, and international knowledge exchange, ensuring that APEC economies remain prepared to capitalize on breakthroughs when they become viable.

- **Watchlist and Monitoring**

Signals with Medium-Low (1–2) or weak medium scores, such as early-stage innovations (*algae power, niche lab-grown products*), are not yet relevant for policy action. These should be kept under systematic horizon scanning and expert dialogue to detect early signs of acceleration or convergence with other drivers.

- **Regional Cooperation Priority**

Some signals—such as hydrogen diplomacy, ASEAN Power Grid integration, border carbon adjustments, and regional MRV-data platforms—carry explicit cross-border implications. These require harmonized standards, shared data systems, and joint investment mechanisms to reduce risks of policy fragmentation. For APEC, these signals express the need to leverage existing regional platforms for policy alignment and cooperative innovation.

In summary, the Policy Matrix demonstrates that APEC economies face a **dual**

policy challenge: (1) to act immediately on high-impact and urgent signals, particularly in energy, governance, and resource security, and (2) to prepare strategically for disruptive technologies and socio-political risks that could shape long-term trajectories. By adopting this structured framework, governments can allocate resources more effectively, strengthen adaptive capacity, and ensure that foresight insights are systematically embedded into policymaking for carbon neutrality.

Table 3 APEC Carbon Neutrality Signals Ranking by Policy Matrix Framework

Policy Category	Policy Orientation	Emerging Signals
Immediate Action	High impact – High urgency – High likelihood	• EV adoption mandates • Smart grid scale-up programs Integrated MRV-data platforms* • Food insecurity* • Global water crisis* • Worker reskilling & transition programs* • Legal mechanisms for net-zero enforcement • Long-term climate action plans with legal backing • Carbon trading & carbon credit systems*
Planned Deployment	High impact – Medium likelihood – Requires phased implementation	• Hydrogen economy* • Hydrogen diplomacy* • Development of regional grid codes* • Battery recycling & circular economy* • Corporate PPAs for clean power • Transition bonds for high-carbon sectors • Nature-based bond frameworks • Regenerative farming
Risk Mitigation	Politically/economically destabilizing – Requires safeguards	• Energy pricing as political trigger • Anti-carbon tax movements • Resource wars (critical minerals & rare earths)* • Massive grid & network outage

Policy Category	Policy Orientation	Emerging Signals
		• Border carbon adjustments* • Climate change–induced diseases*
Strategic Preparedness	Transformative but uncertain – Requires R&D, pilots, monitoring	• Small Nuclear Power Plants (SMR)* • Thorium power plants • CCUS-as-a-service • CO_2 transport & storage infrastructure • Graphene revolution E • V battery revolution • Green AI • Lab-grown foods • Animal-free dairy products • Renewable energy liquids • Algae power
Monitoring / Watchlist	Emerging or weak signals – Ongoing tracking	• Generation Z climate perspectives • Hybridisation of society • Endangered foods • Ocean as strong carbon sink • Microgrids (early-stage contexts) • Energy prosumerism • Peer learning & twinning programs
Regional Cooperation Priority	High spillover effects – Requires cross-border alignment, harmonization, or shared platforms	• Integrated MRV-data platforms • Carbon trading & carbon credit systems • Hydrogen economy & diplomacy • Development of regional grid codes • Border carbon adjustments • Resource wars / critical minerals security • Battery recycling & circular economy • Global water crisis (Water–Energy–Food nexus) • Climate change–induced diseases

		• Worker reskilling & transition programs • Food insecurity & blue carbon finance • Small Modular Reactors (SMR)

Notes: Signals marked with (*) appear in both a **policy-response category** and the **Regional Cooperation Priority** category.

The "Regional Cooperation Priority" row does not replace policy categories — it acts as a **cross- cutting layer** identifying where APEC-level coordination adds strategic value

To systematically prioritize emerging signals affecting carbon neutrality in APEC, a composite Prioritization Index (PI) was constructed based on three assessment dimensions: Impact, Likelihood, and Urgency. These dimensions were rated on a five-point scale by experts across participating economies.

Given that no prior normative justification was established to assign differential weights across dimensions, the three criteria were treated with equal importance. To ensure comparability and to assess each signal relative to the overall distribution of responses, *a mean-normalization approach* was applied.

For each dimension $k \in \{I, L, U\}$, the mean score across all n signals was calculated as:

$$\bar{k} = \frac{1}{n}\sum_{i=1}^{n} k_i$$

Where I_i = average Impact score of signal i, L_i= average Likelihood score of signal i, and U_i = average Urgency score of signal i

Each signal's score was then divided by the corresponding overall mean:

$$I_i^* = \frac{I_i}{\bar{I}}, L_i^* = \frac{L_i}{\bar{L}}, U_i^* = \frac{U_i}{\bar{U}}$$

This transformation produces relative indices**:**

- Values > 1 indicate above-average importance
- Values = 1 indicate average
- Values < 1 indicate below-average

This approach allows the analysis to highlight signals that outperform the overall baseline rather than merely reflecting absolute scale values.

Given that no prior normative justification existed for differential weighting among the three dimensions, equal weighting was applied to calculate Prioritization Index (PI):

$$PI_i = \frac{1}{3}(I_i^* + L_i^* + U_i^*)$$

This ensures methodological transparency and avoids subjective bias in weighting. The resulting PI provides a single composite score for ranking signals across all challenge areas, as show in Table 4.

Table 4 Scoring and Ranking of Signals by Challenge Area

Rank	Challenge Area	Signal	I	L	U	I*	L*	U*	PI
1	**Finance**	**Carbon Trading & Carbon Credit**	**4.4**	**4.4**	**4.5**	**1.17**	**1.24**	**1.24**	**1.22**
2	**Social & Just Transition**	**Worker Reskilling & Transition Programs**	**4.3**	**4.2**	**4.5**	**1.14**	**1.19**	**1.24**	**1.19**
3	**Social & Just Transition**	**Generation Z Climate Perspectives**	**4.1**	**4**	**4.4**	**1.09**	**1.13**	**1.22**	**1.14**
4	**Energy Transition & Technology**	**Corporate PPAs for Clean Power**	**4**	**4.1**	**4.3**	**1.06**	**1.16**	**1.19**	**1.14**
5	**Environment & Natural Resources**	**Food Insecurity**	**4**	**4.1**	**4.3**	**1.06**	**1.16**	**1.19**	**1.14**
6	**Policy & Governance**	**Border Carbon Adjustments**	**4.1**	**3.9**	**4.4**	**1.09**	**1.10**	**1.22**	**1.14**
7	**Policy & Governance**	**Legal Mechanisms for Net-Zero Enforcement**	**4.5**	**3.7**	**4.2**	**1.20**	**1.04**	**1.16**	**1.13**
8	**Data & MRV**	**Integrated MRV-Data Platforms**	**4.1**	**4**	**4.2**	**1.09**	**1.13**	**1.16**	**1.13**
9	**Environment & Natural Resources**	**Global Water Crisis**	**4.1**	**4.2**	**3.9**	**1.09**	**1.19**	**1.08**	**1.12**
10	**Technology & Innovation**	**Zero-Emission Data Centers**	**4.2**	**3.7**	**4.3**	**1.12**	**1.04**	**1.19**	**1.12**
11	Policy & Governance	Long-term Climate Action Plans (Legal)	4.3	3.7	4.1	1.14	1.04	1.13	1.11
12	Policy & Governance	Energy Pricing as Political Trigger	4.3	3.5	4.2	1.14	0.99	1.16	1.10
13	Energy Transition & Technology	EV Adoption Mandates	3.9	4.1	3.9	1.04	1.16	1.08	1.09
14	Energy Transition & Technology	Smart Grid Scale-up Programs	4	3.8	4	1.06	1.07	1.10	1.08
15	Environment & Natural Resources	Resource Wars	4.1	4.1	3.5	1.09	1.16	0.97	1.07
16	Technology & Innovation	EV Battery Revolution	4	3.9	3.8	1.06	1.10	1.05	1.07
17	Data & MRV	Peer Learning & Twinning Programs	4	3.7	3.9	1.06	1.04	1.08	1.06
18	Finance	Transition Bonds (High-carbon Sectors)	4	3.7	3.8	1.06	1.04	1.05	1.05
19	Technology & Innovation	CO_2 Transport & Storage Infrastructure	4	3.4	4.1	1.06	0.96	1.13	1.05
20	Social & Just Transition	Climate Change-Induced Diseases	3.9	3.6	3.9	1.04	1.02	1.08	1.04
21	Technology & Innovation	Green AI	3.9	3.6	3.9	1.04	1.02	1.08	1.04
22	Energy Transition & Technology	Battery Recycling & Circular Economy	4.1	3.4	3.9	1.09	0.96	1.08	1.04
23	Technology & Innovation	Precision & Robotic Agriculture	3.9	3.9	3.5	1.04	1.10	0.97	1.03
24	Policy & Governance	Upgraded APEC Climate Mechanisms	3.9	3.9	3.5	1.04	1.10	0.97	1.03

Rank	Challenge Area	Signal	I	L	U	I*	L*	U*	PI
25	Policy & Governance	EU Taxonomy	3.8	3.6	3.9	1.01	1.02	1.08	1.03
26	Technology & Innovation	CCUS-as-a-service	4.1	3.2	4	1.09	0.90	1.10	1.03
27	Technology & Innovation	Regenerative Agriculture	3.6	3.9	3.7	0.96	1.10	1.02	1.03
28	Energy Transition & Technology	Battery Reuse & Second-Life	4	3.5	3.7	1.06	0.99	1.02	1.02
29	Social & Just Transition	Hybridisation of Society	4	3.2	4	1.06	0.90	1.10	1.02
30	Environment & Natural Resources	Aquaculture & Blue Carbon Credits	3.6	3.8	3.7	0.96	1.07	1.02	1.02
31	Finance	Climate Risk Guarantees	3.8	3.7	3.6	1.01	1.04	0.99	1.02
32	Energy Transition & Technology	Energy Prosumerism	3.9	3.6	3.6	1.04	1.02	0.99	1.02
33	Environment & Natural Resources	Endangered Foods	3.5	3.8	3.6	0.93	1.07	0.99	1.00
34	Environment & Natural Resources	Ocean as Strong Carbon Sink	3.9	3.6	3.4	1.04	1.02	0.94	1.00
35	Technology & Innovation	Mega-Infrastructure for Climate Adaptation	3.9	3.1	3.9	1.04	0.88	1.08	1.00
36	Technology & Innovation	Small Nuclear Power Plants (SMR)	3.8	3.6	3.4	1.01	1.02	0.94	0.99
37	Energy Transition & Technology	Microgrids	3.7	3.4	3.7	0.98	0.96	1.02	0.99
38	Energy Transition & Technology	Hydrogen Economy	3.7	3.3	3.7	0.98	0.93	1.02	0.98
39	Environment & Natural Resources	Carbon Farming	3.6	3.5	3.5	0.96	0.99	0.97	0.97
40	Finance	Environmental & Pigouvian Taxes	3.6	3.5	3.5	0.96	0.99	0.97	0.97
41	Energy Transition & Technology	Hydrogen Diplomacy	3.5	3.4	3.5	0.93	0.96	0.97	0.95
42	Policy & Governance	Regional Climate Data Governance Platforms	3.5	3.3	3.5	0.93	0.93	0.97	0.94
43	Finance	Nature-based Bond Frameworks	3.4	3.2	3.4	0.90	0.90	0.94	0.92
44	Energy Transition & Technology	Development of Regional Grid Codes	3.7	2.9	3.3	0.98	0.82	0.91	0.90
45	Technology & Innovation	Lab-grown Foods	3.4	3.7	2.7	0.90	1.04	0.75	0.90
46	Policy & Governance	Accelerated ASEAN Power Grid	3.5	2.9	3.4	0.93	0.82	0.94	0.90
47	Energy Transition & Technology	Massive Grid & Network Outage	3.5	3.1	3.1	0.93	0.88	0.86	0.89
48	Finance	Anti-carbon Tax Movements	3.5	3.2	2.8	0.93	0.90	0.77	0.87

Rank	Challenge Area	Signal	I	L	U	I*	L*	U*	PI
49	Technology & Innovation	Artificial Meat	3.1	3.6	2.6	0.82	1.02	0.72	0.85
50	Technology & Innovation	Animal-free Dairy	3.1	3.6	2.6	0.82	1.02	0.72	0.85
51	Energy Transition & Technology	Renewable Energy Liquid	3.3	2.8	3	0.88	0.79	0.83	0.83
52	Technology & Innovation	Graphene Revolution	3	3.1	2.8	0.80	0.88	0.77	0.82
53	Technology & Innovation	Thorium Power Plants	3.5	2.8	2.6	0.93	0.79	0.72	0.81
54	Energy Transition & Technology	Ammonia Economy	2.8	3.1	2.9	0.74	0.88	0.80	0.81
55	Energy Transition & Technology	CO_2 Battery	2.8	2.5	2.6	0.74	0.71	0.72	0.72
56	Energy Transition & Technology	Algae Power	2.5	2.2	2.1	0.66	0.62	0.58	0.62

The prioritization analysis reveals a clear pattern in the types of signals perceived as most critical for advancing carbon neutrality across APEC economies. The Top 10 ranked signals are as follows:

4.3.1 Carbon Trading & Carbon Credit

Expansion and deepening of carbon markets as a primary economic instrument for decarbonization. This signal reflects increasing integration of compliance and voluntary carbon markets, cross-border credit trading, and stronger MRV requirements. It directly influences investment flows, cost-effectiveness of mitigation, and regional climate cooperation.

4.3.2 Worker Reskilling & Transition Programs

Large-scale workforce transition mechanisms to support movement from high-carbon to low-carbon industries. Includes vocational retraining, green skills development, and industrial transformation support. Critical for ensuring a just transition and preventing social resistance to decarbonization policies.

4.3.3 Generation Z Climate Perspectives

Rising influence of younger generations on climate policy, ESG expectations, and consumption patterns. This demographic shift is shaping corporate behavior, political priorities, and demand for sustainable products and transparency.

4.3.4 Corporate PPAs for Clean Power

Rapid growth of Corporate Power Purchase Agreements (PPAs) enabling businesses to procure renewable electricity directly. This accelerates private-sector-led decarbonization, supports renewable investment bankability, and reduces dependence on traditional utilities.

4.3.5 Food Insecurity

Climate-induced disruptions in food systems, supply chains, and agricultural productivity. Increasing food insecurity creates political and economic pressures that intersect with mitigation and adaptation strategies.

4.3.6 Border Carbon Adjustments

Implementation of carbon border measures (e.g., CBAM-type mechanisms) that adjust trade flows based on embedded emissions. This affects export competitiveness, industrial policy, and regional supply chains.

4.3.7 Legal Mechanisms for Net-Zero Enforcement

Strengthening of legally binding climate frameworks, climate acts, and enforcement mechanisms. Signals institutional maturation of climate governance and increased accountability in achieving long-term net-zero targets.

4.3.8 Integrated MRV-Data Platforms

Development of interoperable digital MRV systems linking economies inventories, corporate reporting, and carbon markets. Enables transparency, data reliability, and cross-economy comparability within APEC.

4.3.9 Global Water Crisis

Escalating water scarcity driven by climate change, affecting energy systems (cooling, hydropower), agriculture, and industrial production. Introduces cross-sectoral risk to carbon neutrality pathways.

4.3.10 Zero-Emission Data Centers

Rapid growth in digital infrastructure requiring decarbonized electricity, energy efficiency innovation, and advanced cooling systems. Highlights the interaction between digitalization and energy transition.

4.4 Signals Classification and Prioritization

Signals classification and prioritization constitute a critical step in foresight-based analysis, as they enable policymakers and stakeholders to move beyond simple observation of trends toward structured anticipation and strategic decision-making. In the context of carbon neutrality—where uncertainty, technological disruption, and systemic risks are particularly pronounced—not all emerging developments require the same level of policy attention. For this reason, the signal identification and prioritization process was conducted through an interactive and facilitated workshop, allowing participants from APEC economies to collaboratively interpret, assess, and prioritize emerging signals within a structured and transparent framework.

The ***APEC Foresight Workshop on the Identification of Emerging Signals Affecting Carbon Neutrality***, held on 26–27 November 2025 in Bangkok, Thailand, brought together a diverse group of experts and stakeholders from across the region. A total of ***36 participants*****,** including speakers and attendees, took part in the workshop. Among them, ***17 participants were female (47.2%) and 19 were male (52.8%),*** reflecting a relatively balanced gender representation. Participants represented several APEC economies, including ***Australia; Brunei Darussalam; Indonesia; the Republic of Korea; Malaysia; Peru; Chinese Taipei; and Thailand;*** enabling the workshop to capture a broad range of regional perspectives on carbon neutrality challenges and opportunities, as illustrated in Figure 4.

The primary objective of this workshop-based process was to facilitate collective sensemaking and translate diverse expert insights into a shared understanding of which emerging signals are most relevant to carbon neutrality pathways in the APEC region. By embedding the analytical process within a participatory workshop setting, the exercise strengthened foresight capacity among participants, promoted cross-economy learning, and ensured that the resulting priorities reflected both technical expertise and real-world policy considerations. This collaborative approach also enhanced the legitimacy and policy relevance of the identified signals, supporting more informed and forward-looking climate strategies across APEC economies.

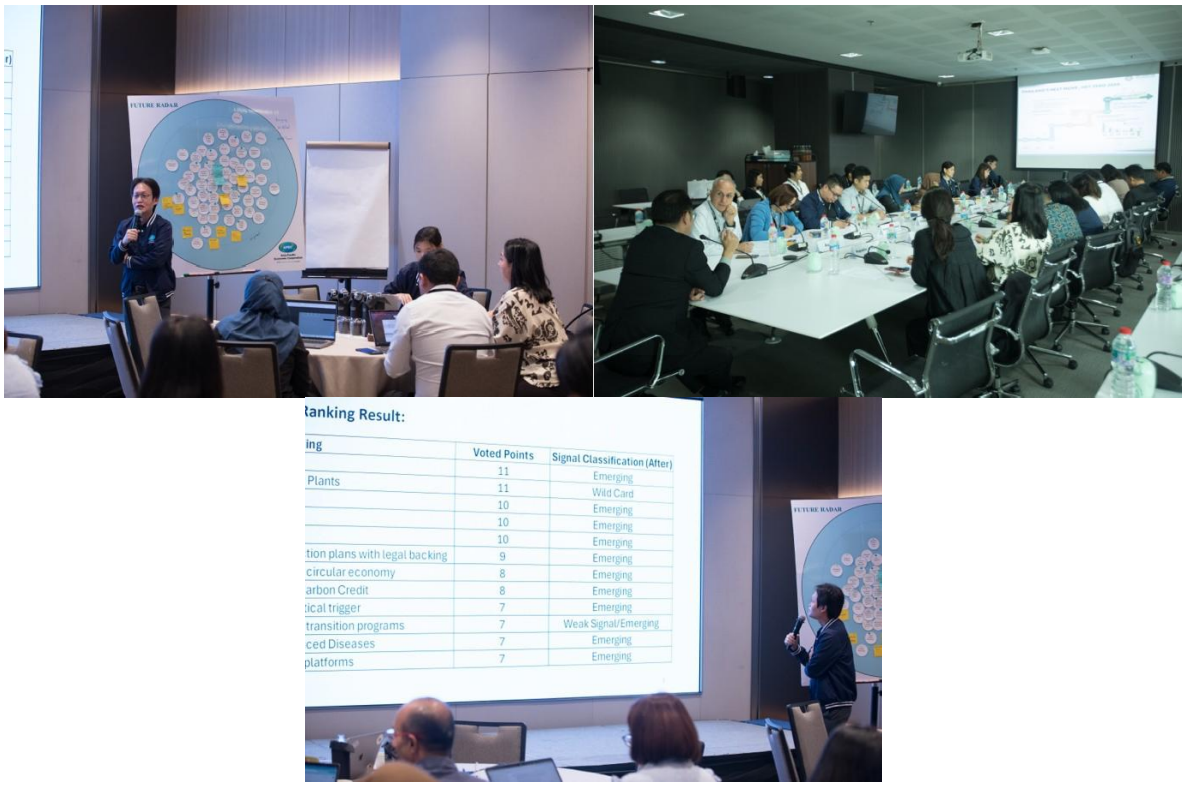

Figure 4 APEC Foresight Workshop on the Identification of Emerging Signals Affecting Carbon Neutrality

The signals classification was guided by foresight principles that emphasize uncertainty, maturity, and transformational potential rather than probability alone. During facilitated group sessions, participants collaboratively reviewed and classified signals into three categories.

- **Weak signals** were defined as early and fragmented indications of potential future change that are not yet widely recognized but may evolve into significant trends.
- **Strengthening signals** referred to developments that are already gaining visibility and momentum, supported by emerging evidence, pilot applications, or increasing policy and market attention.
- **Wild cards** were characterized as low-probability but high-impact events that could fundamentally disrupt economic systems, technologies, or governance structures, and therefore require early awareness and contingency thinking despite their uncertainty.

Following classification, the workshop progressed to a **collective prioritization exercise**, in which participants assessed signals based on their relevance to carbon neutrality, potential systemic impact, and implications for policy and implementation. Through structured discussion, group deliberation, and consensus-building, the initial long list of signals was narrowed down to a smaller set of critical signals for deeper analysis and policy reflection as follows.

4.4.1 Food Insecurity

Signal classification: Emerging

Food insecurity was classified as an **emerging signal**, reflecting its increasing visibility and growing systemic relevance across APEC economies. Climate variability, supply-chain disruptions, rising input costs, and demographic pressures are converging to heighten risks to food availability and affordability. While food insecurity has long existed in parts of the region, recent developments indicate a shift from localized or episodic challenges toward broader structural vulnerability.

In the APEC context, the emerging nature of this signal highlights food security as a forward-looking policy concern that demands anticipatory action. Without coordinated regional responses—such as climate-resilient agriculture, technology adoption by SMEs, and cross-border food supply cooperation—food insecurity risks escalating into a constraint on economic stability, social cohesion, and political trust.

4.4.2 Small Nuclear Power Plants

Signal classification: Wild Card

Small Nuclear Power Plants (including Small Modular Reactors) were classified as a **wild card signal**, indicating low predictability but potentially transformative impacts. Interest in SMRs is growing in response to rising electricity demand from digitalization and data centers, yet deployment remains highly uncertain due to regulatory complexity, public acceptance, safety concerns, and waste management challenges.

For APEC economies, the wild card classification underscores SMRs as a technology pathway that could rapidly reshape energy systems if conditions align—or conversely generate major disruption if mismanaged. This signal calls for contingency planning, regional dialogue on governance and safety, and foresight-based monitoring rather than immediate large-scale policy commitment.

4.4.3 Hydrogen Economy

Signal classification: Emerging

The hydrogen economy was classified as an **emerging signal**, reflecting strong strategic interest alongside unresolved economic and institutional barriers. Hydrogen is increasingly viewed as critical for decarbonizing hard-to-abate sectors, yet high costs, infrastructure gaps, and fragmented policy frameworks limit near-term deployment across APEC economies.

Within APEC, the emerging classification suggests hydrogen is transitioning from conceptual ambition to early experimentation. Regional coordination on standards, certification, and cross-border value chains will play a decisive role in determining whether hydrogen evolves into a scalable regional solution or remains confined to economies' initiatives.

4.4.4 Resource Wars

Signal classification: Emerging

Resource wars were classified as an **emerging signal**, reflecting rising geopolitical tensions and strategic competition over critical minerals essential to the energy transition. Export restrictions, supply concentration, and environmental constraints are increasing awareness of resource security risks, particularly for EVs, batteries, and renewable technologies.

In the APEC context, this emerging signal highlights a shift from abstract geopolitical risk to a tangible policy concern. As competition for minerals intensifies, APEC

economies face growing pressure to diversify supply, develop recycling capacity, and strengthen domestic value chains. Early recognition of this signal provides an opportunity to mitigate conflict risks through cooperation rather than reactive crisis management.

4.4.5 Global Water Crisis

Signal classification: Emerging

The global water crisis was classified as an **emerging signal**, indicating mounting stress on water systems without yet reaching irreversible thresholds in all economies. Climate change, population growth, and competing sectoral demands are increasing water scarcity risks across many APEC members, particularly in agriculture- and energy-intensive regions.

For APEC economies, the emerging classification emphasizes water as a forward-looking constraint on development and decarbonization. Treating water scarcity through integrated Water–Energy–Food Nexus planning and transboundary governance mechanisms is essential to prevent future systemic shocks that could undermine both mitigation and adaptation goals.

4.4.6 Long-Term Climate Action Plans with Legal Backing

Signal classification: Emerging

Long-term climate action plans with legal backing were classified as an **emerging signal**, reflecting growing momentum toward institutionalizing climate commitments. While only a subset of APEC economies currently has legally binding frameworks, interest in durable governance mechanisms is increasing.

In the APEC context, this emerging signal highlights a transition phase in climate governance. Economies that move early toward legally anchored plans may gain advantages in investment credibility and policy continuity, while others risk lagging behind. The signal underscores the value of peer learning within APEC on legislative design and institutional arrangements.

4.4.7 Battery Recycling and Circular Economy

Signal classification: Emerging

Battery recycling and the circular economy were classified as an **emerging signal**, driven by accelerating EV deployment and rising awareness of material supply risks. Although recycling technologies and policies are advancing, large-scale systems are not yet fully established across most APEC economies.

The emerging classification suggests that decisive action in the near term could shape long-run outcomes. For APEC, regional cooperation can help overcome scale limitations, reduce costs, and transform recycling from an environmental obligation into a strategic industrial opportunity supporting resource security and job creation.

4.4.8 Carbon Trading and Carbon Credit

Signal classification: Emerging

Carbon trading and carbon credits were classified as an **emerging signal**, reflecting expanding policy interest but uneven market maturity. Many APEC economies are experimenting with carbon pricing instruments, yet challenges related to MRV, market integrity, and liquidity persist.

In the APEC context, the emerging classification signals that carbon markets are approaching a critical development stage. Early alignment on standards, transparency, and capacity building can help avoid fragmented markets and credibility risks, positioning carbon trading as an effective regional mitigation tool.

4.4.9 Energy Pricing as a Political Trigger

Signal classification: Emerging

Energy pricing as a political trigger was classified as an **emerging signal**, highlighting growing sensitivity to energy affordability during the low-carbon transition. Price volatility and subsidy reforms increasingly intersect with social and political dynamics across APEC economies.

The emerging nature of this signal indicates rising risk rather than inevitable crisis. Proactive communication, demand-side management, and social protection measures can help prevent energy pricing from becoming a destabilizing force that undermines public support for decarbonization.

4.4.10 Worker Reskilling and Transition Programs

Signal classification: Weak Signal / Emerging

Worker reskilling and transition programs were classified as a **weak signal transitioning toward emerging**, suggesting that impacts are beginning to materialize but remain uneven across economies. Skills mismatches and employment disruption are becoming more visible as decarbonization accelerates in energy- and carbon-intensive sectors.

For APEC economies, this classification highlights a narrowing window for early intervention. Investing in reskilling systems now can prevent future social disruption and support inclusive growth, while delayed action risks turning labor transition into a major bottleneck for carbon neutrality.

4.4.11 Climate Change-Induced Diseases

Signal classification: Emerging

Climate change-induced diseases were classified as an **emerging signal**, reflecting increasing scientific evidence but limited integration into climate policy. Changing temperatures, extreme weather, and migration patterns are altering disease dynamics, particularly in tropical and subtropical APEC economies.

The emerging classification emphasizes the need for anticipatory action. Strengthening regional surveillance, data sharing, and health system preparedness can significantly reduce long-term human and economic costs associated with climate-related health risks.

4.4.12 Integrated MRV-Data Platforms

Signal classification: Emerging

Integrated MRV-data platforms were classified as an **emerging signal**, underscoring their growing importance as enabling infrastructure for climate governance. Fragmented data systems currently limit the effectiveness of carbon markets, finance mechanisms, and international reporting.

For APEC economies, this emerging signal highlights the strategic value of investing early in interoperable MRV systems. Regional collaboration on standards and capacity building can enhance transparency, reduce reporting burdens, and support credible progress toward carbon neutrality.

4.5 Integration of Survey and Workshop Signal Priorities

To consolidate the findings from both quantitative (survey-based) and qualitative (workshop-based) prioritization processes, overlapping signals between the Survey Top 10 and the Workshop 12 were identified and merged into a single integrated list. Signals appearing in both processes were treated as high-confidence critical signals and listed only once in the final table below.

After removing duplication, the integrated set contains **17 critical signals**, representing those most consistently identified as strategically significant for carbon neutrality across APEC economies, as shown in Table 5.

Table 5 Integrated Critical Signals

No.	Signal	Challenge Area	Identified Through
1	Carbon Trading & Carbon Credit	Finance	Survey & Workshop
2	Worker Reskilling & Transition Programs	Social and Just Transition	Survey & Workshop
3	Long-term Climate Action Plans (Legal)	Policy and Governance	Survey & Workshop
4	Integrated MRV-Data Platforms	Data & MRV	Survey & Workshop
5	Food Insecurity	Environment and Natural Resources	Survey & Workshop
6	Global Water Crisis	Environment and Natural Resources	Survey & Workshop
7	Legal Mechanisms for Net-Zero Enforcement	Policy and Governance	Survey
8	Generation Z Climate Perspectives	Social and Just Transition	Survey
9	Corporate PPAs for Clean Power	Energy Transition and Technology	Survey
10	Border Carbon Adjustments	Policy and Governance	Survey
11	Zero-Emission Data Centers	Technology and Innovation	Survey
12	Small Nuclear Power Plants (SMR)	Technology and Innovation	Workshop

No.	Signal	Challenge Area	Identified Through
13	Hydrogen Economy	Energy Transition and Technology	Workshop
14	Resource Wars	Environment and Natural Resources	Workshop
15	Battery Recycling & Circular Economy	Energy Transition and Technology	Workshop
16	Energy Pricing as Political Trigger	Policy and Governance	Workshop
17	Climate Change-Induced Diseases	Social and Just Transition	Workshop

This integrated set reflects a triangulated assessment combining quantitative prioritization (mean-normalized composite index) and qualitative deliberative validation. The analytical value of this integration lies not only in identifying which signals rank highly, but also in understanding why they emerge across different methodological lenses.

4.5.1 High-Confidence Signals: Convergence Across Methods

Six signals were identified through both the survey and workshop processes, i.e., Carbon Trading & Carbon Credit, Worker Reskilling & Transition Programs, Long-term Climate Action Plans (Legal), Integrated MRV-Data Platforms, Food Insecurity, and Global Water Crisis.

The convergence of these signals across both quantitative scoring and participatory deliberation indicates strong consensus regarding their structural importance. These signals combine high perceived impact with practical relevance and immediate policy implications. They represent systemic enablers (carbon markets, legal frameworks, MRV systems), socio-economic transition mechanisms (reskilling), and cross-sectoral environmental risks (food and water security). Their dual validation suggests they form the core backbone of the regional carbon neutrality transition agenda.

4.5.2 Survey-Driven Signals: Market and Governance Instruments

Signals identified through the survey, such as Legal Mechanisms for Net-Zero Enforcement, Generation Z Climate Perspectives, Corporate PPAs for Clean Power, Border Carbon Adjustments, and Zero-Emission Data Centers, reflect dimensions that scored consistently high across Impact, Likelihood, and Urgency. These signals emphasize institutional certainty, regulatory enforcement, private-sector energy procurement mechanisms, trade-related climate instruments, and emerging infrastructure demands linked to digitalization. Their prominence in the survey suggests that experts perceive structured policy instruments and market-aligned mechanisms as central drivers of decarbonization.

Notably, Zero-Emission Data Centers signal an emerging recognition that digital infrastructure—often overlooked in traditional energy transitions—constitutes a rapidly growing emissions frontier requiring early strategic attention.

4.5.3 Workshop-Driven Signals: Geopolitical and Systemic Risk Emphasis

Signals highlighted uniquely through the workshop process include Small Nuclear Power Plants (SMR), Hydrogen Economy, Resource Wars, Battery Recycling & Circular Economy, Energy Pricing as Political Trigger, and Climate Change-Induced Diseases.

These signals reflect deliberative concerns that extend beyond scoring metrics. Participants emphasized geopolitical competition over critical minerals, technological uncertainty in next-generation energy systems, political economy instability linked to energy pricing, and climate-induced health risks. These dimensions often involve complex interdependencies and long-term uncertainties that may not be fully captured through quantitative scoring alone.

The workshop process thus surfaced systemic vulnerabilities and geopolitical risks that complement the more structured policy instruments identified in the survey.

5 Key Messages and Recommendations

5.1 Conceptual Framework for Thematic Structuring

Achieving carbon neutrality in the APEC region requires more than a collection of sectoral policies or technology-specific interventions. It demands a systemic transformation across interconnected economic, technological, ecological, institutional, and social domains. For this reason, the strategic themes guiding APEC's carbon neutrality agenda are structured using a **"System Architecture of Carbon Neutrality"** approach. This framework conceptualizes decarbonization as a multi-layered system transformation process rather than a set of isolated mitigation measures.

This conceptualization draws on the socio-technical transition literature, particularly the Multi-Level Perspective (MLP), which views systemic transformation as the interaction between niche innovations, incumbent regimes, and broader landscape pressures [18]. In this framework, technological innovations such as hydrogen, SMRs, and advanced recycling systems emerge within niches; governance structures and market mechanisms represent the regime; and climate risks, geopolitical tensions, and demographic shifts operate at landscape level. Carbon neutrality occurs when alignment across these layers enables structural reconfiguration of the system.

Similarly, the Intergovernmental Panel on Climate Change (IPCC) emphasizes a systems-based approach to mitigation, highlighting that [19] effective decarbonization pathways require coordination across energy systems, land systems, urban systems, industry, finance, and institutional governance [19]. The IPCC underscores that mitigation feasibility is shaped not only by technology availability, but also by political, economic, and social enablers. Therefore, thematic structuring must reflect functional system components rather than administrative sectors alone.

Furthermore, insights from political economy research reinforce the importance of institutional credibility and social stability in sustaining climate transitions. Evidence from energy subsidy reform and carbon pricing initiatives demonstrates that poorly managed transitions can trigger public backlash and policy reversals [20, 21]. This

underscores the necessity of [20] distinguishing between governance architecture and political economy stabilization as separate but interdependent strategic dimensions.

The ecological dimension is equally critical. The Planetary Boundaries framework and the Water–Energy–Food Nexus literature [23] demonstrate that biophysical constraints—such as water scarcity, biodiversity loss, and mineral depletion—can act as binding limits on economic and technological systems. Decarbonization pathways that ignore ecological interdependencies risk triggering systemic disruptions that undermine climate objectives.

APEC is a voluntary, diverse regional platform encompassing advanced, emerging, and developing economies. Unlike regulatory blocs, APEC operates through consensus, peer learning, and cooperative capacity building. A sectoral or narrowly technological framing would inadequately capture the complexity and interdependence of member economies. The system architecture approach offers several advantages:

1. **Cross-economy flexibility:** Themes are functional rather than sector-bound, allowing adaptation to different contexts of each economy.
2. **Integration of STI and governance:** It aligns with APEC's emphasis on science, technology, and innovation (STI).
3. **Policy coherence:** It clarifies causal relationships between innovation, institutions, and social legitimacy.
4. **Scenario compatibility:** The layered structure supports foresight analysis by identifying potential weak points in different pathways.

Ultimately, this framework positions carbon neutrality not as an environmental objective alone, but as a comprehensive structural transformation of economic systems, governance institutions, ecological management, and social contracts.

Based on these conceptual foundations, APEC's strategic policy themes are structured around five system layers that collectively constitute the architecture of carbon neutrality:

1) Energy System Transformation and Technology Pathways

This layer represents the physical transformation engine of carbon neutrality within APEC. It encompasses advanced low-carbon supply technologies and enabling market mechanisms—such as hydrogen systems, small modular reactors (SMRs), battery recycling and circular energy materials, zero-emission data centers, and corporate PPAs for clean power—that collectively reshape generation, storage, and end- use demand patterns. In socio-technical transition terms, these signals reflect niche innovations and demand-side shifts capable of reconfiguring incumbent energy regimes. Strategic coordination under this theme prioritizes technology governance, safety and certification standards, hydrogen corridor development, circular mineral strategies, grid modernization, and alignment between digitalization-driven electricity demand and clean power deployment.

2) Resource Security and Ecological Constraints

This layer addresses the biophysical boundaries within which decarbonization must occur. Food insecurity, global water stress, and geopolitical competition over critical minerals highlight how ecological pressures can act as structural constraints on energy transition. Without integrated Water–Energy–Food–Minerals nexus planning, climate mitigation efforts risk intensifying resource depletion or triggering instability. This theme emphasizes anticipatory risk management, climate-resilient agriculture, responsible mineral governance, and regional cooperation mechanisms to prevent

ecological stress from becoming systemic economic or geopolitical disruption. It reflects the IPCC's emphasis on cross-sectoral interdependence and the need to operate within planetary limits.

3) Climate Governance, Markets, and Institutional Architecture

This layer constitutes the institutional backbone of APEC's carbon neutrality pathway. Legally anchored net-zero mechanisms, long-term climate action plans, integrated MRV-data platforms, carbon trading systems, border carbon adjustments, and market instruments such as corporate PPAs collectively provide credibility, transparency, and predictable investment signals. Robust governance architecture reduces transaction costs, strengthens market integrity, and enables cross-border interoperability. Without durable legal frameworks and data integrity, technological innovation cannot scale efficiently. This theme draws from institutional governance theory and feasibility analysis in climate transition research, emphasizing the alignment of markets, regulation, and finance.

4) Political Economy and Transition Stability

This layer recognizes that decarbonization is embedded within economic and geopolitical realities. Energy pricing dynamics, trade impacts of border carbon measures, and tensions over resource security can influence public acceptance and macroeconomic stability. Political economy research demonstrates that reforms perceived as inequitable or abrupt often provoke backlash and policy reversals. Therefore, this theme focuses on sequencing pricing reforms, incorporating social safeguards, managing competitiveness concerns, and enhancing regional dialogue on energy security. Ensuring affordability, transparency, and fairness is essential to maintaining sustained transition momentum.

5) Human Security and Just Transition

The final layer centers on social resilience and intergenerational legitimacy. Worker reskilling and transition programs, climate change-induced diseases, Generation Z climate perspectives, and the human dimension of food insecurity collectively shape whether decarbonization strengthens or fragments social cohesion. A just transition framework emphasizes inclusive labor adaptation, public health preparedness, youth engagement, and protection of vulnerable communities. Aligning climate policy with social equity principles enhances long-term legitimacy and stability, consistent with OECD and ILO guidance on equitable green transitions. This layer ensures that carbon neutrality advances human development rather than undermining it.

5.2 Policy Recommendations

The prioritization of the 17 signals across APEC economies underscores that carbon neutrality requires a coordinated, system-wide response rather than isolated sectoral measures. The analysis reveals interlinked challenges spanning energy transformation, resource security, governance credibility, political economy stability,

and social resilience. In response, the policy recommendations are organized under five strategic themes as follows.

5.2.1 Theme 1: Energy System Transformation and Technology Pathways

The transformation of APEC's energy systems represents the foundational engine of carbon neutrality. Decarbonization across transport, industry, buildings, and digital infrastructure ultimately depends on the availability of reliable, affordable, and low-carbon energy. However, the region faces heterogeneous starting points: some economies possess advanced nuclear and hydrogen capabilities, while others remain reliant on fossil fuels and imported energy resources. A strategic and coordinated approach is therefore essential.

This theme focuses on three core technological pillars—advanced low-carbon baseload power (e.g., SMRs), hydrogen systems, and circular energy-material integration (e.g., battery recycling)—while recognizing their interdependence with investment signals, certification systems, and infrastructure planning.

(1) Establish an APEC Low-Carbon Energy Technology Coordination Platform

Emerging technologies such as hydrogen and SMRs face uneven regulatory readiness, fragmented standards, and duplicated R&D efforts across APEC economies. Without coordination, this fragmentation increases costs and delays commercialization.

APEC should establish a Low-Carbon Energy Technology Coordination Platform under PPSTI or EWG that:

- Facilitates joint foresight and technology roadmapping
- Aligns technical standards and safety frameworks
- Supports demonstration and pilot project exchanges
- Promotes interoperability of hydrogen certification and nuclear governance practices.

This platform would not impose harmonized regulation but would reduce uncertainty and accelerate diffusion by improving transparency and knowledge sharing.

(2) Accelerate Regional Hydrogen Value Chain Development

Hydrogen is essential for decarbonizing hard-to-abate sectors (steel, chemicals, heavy transport). However, green hydrogen remains cost-prohibitive in many APEC economies, and infrastructure for storage, transport, and certification is fragmented.

APEC should:

1. Develop a Regional Hydrogen Corridor Initiative
    - Identify strategic production–demand clusters
    - Coordinate port infrastructure and shipping logistics
    - Share best practices on hydrogen safety regulations
2. Promote a Mutual Recognition Framework for Hydrogen Certification
    - Align methodologies for emissions accounting
    - Integrate MRV systems for cross-border trade
    - Reduce transaction costs for exporters and importers
3. Mobilize Green Finance for Hydrogen Scaling
    - Use blended finance models

- Establish risk-sharing mechanisms for first-of-a-kind projects

These actions can reduce capital risk, accelerate economies of scale, and prevent regulatory divergence.

(3) Develop a Circular Energy Materials Strategy

Energy transition technologies depend on critical minerals such as lithium, nickel, cobalt, and rare earth elements. Over-reliance on primary extraction increases geopolitical vulnerability and environmental risk.

APEC should adopt a *Regional Circular Energy Materials Strategy* that:

- Harmonizes Extended Producer Responsibility (EPR) principles for batteries
- Encourages joint recycling facilities for economies lacking scale
- Supports open innovation or patent-pooling mechanisms for recycling technologies
- Integrates battery recycling into critical mineral security planning.

By linking circular economy strategies with energy transition planning, APEC can reduce import dependency while generating new industrial opportunities.

(4) Enhance System Integration and Grid Modernization

Electrification and renewable integration increase system complexity. Without grid modernization, energy storage, and smart demand management, decarbonization can threaten reliability and affordability.

APEC should:

- Promote smart grid interoperability standards
- Support digitalization of grid systems
- Facilitate cross-border knowledge sharing on storage integration
- Encourage demand-side flexibility mechanisms

Grid modernization must accompany hydrogen and electrification strategies to ensure system stability.

(5) Manage Risks in Advanced Nuclear Deployment

Small Modular Reactors (SMRs) represent a potential breakthrough in reliable low-carbon baseload power but remain uncertain due to public acceptance, safety governance, and waste management concerns.

Rather than immediate large-scale endorsement, APEC should:

- Facilitate transparent regional dialogue on SMR safety and waste traceability
- Promote shared learning from economies with operational experience
- Develop contingency planning frameworks to manage rapid deployment scenarios

This approach allows preparedness without prematurely locking in capital-intensive pathways.

(6) Strengthen Investment Signals and Market Alignment

Technology transformation cannot occur without stable policy signals. Carbon markets, long-term climate commitments, and MRV systems influence private-sector capital allocation.

Under this theme, APEC should:

- Align carbon market standards with hydrogen and clean power certification

- Improve transparency in energy transition investment data
- Support green bond and blended finance mechanisms targeting energy infrastructure

Investment coherence reduces capital costs and accelerates deployment.

Cross-cutting considerations highlight that the energy transition must be managed not only as a technological shift but as a socially and politically sensitive transformation. Ensuring equity and inclusiveness is critical so that advanced APEC economies do not outpace developing members, making capacity-building and technology transfer essential to prevent widening development gaps. At the same time, political feasibility must guide reform sequencing—particularly in energy pricing and subsidy restructuring—to avoid public backlash that could delay or derail technological deployment. Finally, given high levels of uncertainty, including potential mineral supply disruptions or rapid AI-driven energy demand growth, policymakers must adopt flexible and adaptive frameworks capable of responding effectively to multiple future scenarios rather than relying on fixed, linear planning approaches.

If implemented effectively, *Energy System Transformation* would strengthen APEC's regional energy security, lower clean technology costs through cooperation and scale, enhance resilience against geopolitical disruptions, and position the region as a global leader in coordinated clean energy innovation. More than a technological upgrade, it represents the structural foundation underpinning APEC's long-term carbon neutrality pathway.

5.2.2 Theme 2: Resource Security and Ecological Constraints

Carbon neutrality cannot be achieved in isolation from the biophysical systems that sustain economic activity. Food production depends on water availability and land quality; renewable technologies depend on critical minerals; industrial expansion depends on ecological stability. Within APEC, the interdependence of food security, water systems, and mineral supply chains presents both structural risks and strategic opportunities.

This theme recognizes that ecological constraints are not peripheral environmental concerns but binding system conditions for sustainable decarbonization. If resource governance fails, energy transformation may stall, geopolitical tensions may rise, and social stability may weaken.

Accordingly, APEC must adopt an integrated resource-security strategy anchored in three pillars: food resilience, water governance, and critical mineral stability.

(1) Strengthen Regional Food System Resilience

Food insecurity in APEC would be increasingly shaped by climate shocks, supply chain fragility, demographic shifts, and geopolitical trade disruptions. As climate variability intensifies, agricultural productivity becomes more volatile, affecting both producers and consumers.

APEC should:

1. Develop an **APEC Food Resilience Framework**
    - Promote climate-resilient staple crop research (e.g., drought-tolerant rice)
    - Encourage diffusion of digital agriculture tools for SMEs
    - Strengthen regional emergency food supply coordination
2. Facilitate **G2G Food Supply Cooperation Mechanisms**

- Establish early-warning systems for supply disruptions
- Enhance transparency in agricultural trade flows
- Reduce non-tariff barriers during crisis periods

3. Promote Blue Economy Integration
   - Support sustainable marine protein development
   - Link coastal ecosystem protection with food security strategies

Food resilience must be framed not only as an agricultural issue but as a pillar of economic and political stability across APEC.

(2) Adopt an Integrated Water–Energy–Food Nexus Approach

Water scarcity is intensifying across many APEC economies due to climate change, urbanization, and industrial expansion. Water stress affects hydropower, cooling systems for thermal plants, agricultural productivity, and public health. Without coordinated governance, water constraints could undermine both mitigation and adaptation efforts.

APEC should:

1. Promote *Integrated Water-Energy-Food Nexus Planning Tools*
   - Develop scenario-based planning methodologies
   - Encourage cross-ministerial coordination within economies
2. Strengthen Transboundary Water Cooperation
   - Share best practices from river basin management experiences
   - Support joint monitoring and data-sharing mechanisms
3. Encourage Water-Efficient Industrial Standards
   - Develop guidelines for water-efficient data centers
   - Promote water-saving technologies in agriculture and energy production

By institutionalizing nexus governance, APEC can reduce the risk of cascading failures across food, energy, and economic systems.

(3) Enhance Critical Mineral Security and Clean Mining Governance

The energy transition will significantly increase demand for lithium, cobalt, nickel, and rare earth elements. APEC economies collectively account for a large share of global reserves and production. However, concentrated supply chains and export restrictions increase geopolitical risk.

APEC should:

1. Develop a *Clean Mining and Responsible Resource Governance Framework*
   - Establish environmental and community engagement standards
   - Encourage transparency in mineral supply chains
2. Promote Regional Value-Chain Development
   - Support domestic processing and refining capabilities
   - Facilitate technology transfer for mineral upgrading
3. Integrate Recycling into Mineral Security Strategy
   - Link battery recycling initiatives with mineral supply planning
   - Encourage “urban mining” as a complementary source of critical materials
4. Enhance Supply Diversification and Risk Monitoring
   - Establish a regional mineral supply risk observatory
   - Conduct foresight exercises on geopolitical disruption scenarios

Critical mineral governance must balance economic opportunity with environmental integrity and social acceptance.

(4) Integrate Ecological Risk into Climate Policy Design

Resource stress can amplify political instability, migration, and economic volatility. Climate mitigation strategies that ignore ecological limits may inadvertently exacerbate vulnerabilities.

APEC should:

- Require ecological risk assessments in major energy transition investments
- Promote nature-based solutions that align mitigation with ecosystem restoration
- Integrate biodiversity protection into carbon finance mechanisms

This ensures that decarbonization pathways remain aligned with broader sustainability objectives.

APEC's carbon neutrality pathway must address broader systemic risks that cut across all themes. First, *geopolitical stability* is essential, as competition over energy and critical resources can intensify trade tensions; APEC's cooperative platform can help mitigate these risks through dialogue and transparency. Second, *equity and inclusiveness* must be embedded in governance frameworks, ensuring that vulnerable communities affected by resource extraction and climate impacts are protected through participatory and benefit-sharing mechanisms. Third, building *long-term structural resilience* is critical, as gradual resource constraints can lead to sudden systemic disruptions; early adoption of nexus-based planning and institutional coordination can reduce future transition costs and enhance stability.

If effectively implemented, Theme 2 will reduce systemic risks arising from ecological constraints, strengthen the resilience of food and water systems, enhance mineral security for clean technologies, and prevent resource competition from destabilizing regional cooperation. Resource security and ecological constraints are not peripheral environmental concerns; they define the structural boundaries within which carbon neutrality must be achieved. Robust governance in this area ensures that APEC's decarbonization pathway remains economically viable, socially stable, and environmentally sustainable over the long term.

5.2.3 Theme 3: Climate Governance, Markets & Institutional Architecture

Carbon neutrality depends not only on technology deployment but on the credibility, durability, and transparency of governance systems. Without enforceable long-term climate commitments, credible carbon markets, and interoperable MRV (Measurement, Reporting, and Verification) systems, investment signals remain weak and fragmented.

Within APEC, institutional readiness varies significantly across economies. Some members have legally binding net-zero frameworks and advanced carbon pricing mechanisms, while others rely on voluntary commitments or pilot initiatives. Bridging these differences requires coordinated but flexible institutional cooperation.

(1) Strengthen Legal and Institutional Foundations for Carbon Neutrality Commitments

Long-term climate action plans anchored in legislation provide predictability for investors and policy continuity beyond political cycles.

APEC should:

- Promote peer-learning dialogues on legally backed climate frameworks
- Develop voluntary guidelines on minimum institutional elements for net-zero governance
- Encourage alignment between economies' climate laws and long-term economic development plans

Rather than imposing harmonization, APEC can serve as a platform for institutional benchmarking and mutual learning.

(2) Enhance Carbon Market Integrity and Interoperability

Carbon trading and carbon credit systems are expanding across the region, but fragmentation, data opacity, and verification costs limit effectiveness.

APEC should:

- Develop a voluntary *Carbon Market Interoperability Framework*
  - Align accounting methodologies
  - Promote transparency in credit issuance and retirement
- Encourage knowledge-sharing on managing price volatility and market stability
- Promote safeguards against greenwashing through stronger verification standards

APEC can help reduce transaction costs and increase confidence in carbon finance.

(3) Build Integrated and Interoperable MRV Systems

MRV systems form the backbone of credible climate governance. Fragmented data architectures undermine policy coherence and carbon market effectiveness.

APEC should:

- Promote interoperable MRV data standards across sectors (energy, industry, land use)
- Support digital MRV innovation (e.g., blockchain, AI-assisted verification)
- Facilitate capacity building for economies with limited technical infrastructure

Integrated MRV systems enable cross-border cooperation in hydrogen certification, carbon markets, and climate finance.

(4) Align Finance with Climate Governance Architecture

Capital flows respond to credible governance signals. Weak institutional design increases financing costs.

APEC should:

- Encourage green bond frameworks aligned with regional climate standards
- Support blended finance mechanisms for emerging technologies
- Enhance disclosure practices for climate-related financial risks

Strong institutional architecture lowers investment uncertainty and accelerates technology deployment.

Effective governance architecture will increase investor confidence, enhance policy coherence, strengthen cross-border climate cooperation, and reduce institutional fragmentation across APEC economies. As the institutional backbone of the carbon neutrality framework, Theme 3 ensures that technological transformation and market

mechanisms operate within a credible, transparent, and interoperable system—thereby enabling durable and coordinated regional progress toward net-zero emissions.

5.2.4 Theme 4: Political Economy and Transition Stability

Decarbonization is not only a technical or environmental transformation—it is fundamentally a political and economic restructuring process. Energy pricing reforms, carbon markets, trade-related climate measures, and subsidy removal can trigger public backlash if distributional impacts are not carefully managed. Therefore, managing transition stability is critical to sustaining long-term policy momentum.

(1) Develop a Framework for Gradual and Predictable Energy Pricing Reform

Energy pricing reforms—particularly fossil fuel subsidy removal and carbon pricing introduction—should be implemented in a sequenced and transparent manner. Sudden price shocks often trigger public resistance and erode trust in climate policy.

APEC should promote:

- Phased reform roadmaps with clear timelines
- Transparent communication strategies explaining long-term benefits
- Predictable price corridors to reduce volatility
- Revenue recycling mechanisms (e.g., targeted transfers, green investment funds)

This reduces political backlash while maintaining reform credibility.

(2) Integrate Social Protection Mechanisms into Climate Policy Design

Affordability concerns are central to transition stability. Energy price increases, carbon taxation, and trade-adjustment measures disproportionately affect low-income households and energy-intensive SMEs.

APEC should encourage economies to:

- Embed targeted compensation schemes (cash transfers, energy vouchers)
- Protect SMEs during CBAM-related trade shifts
- Design "just compensation packages" for affected sectors
- Develop early-warning systems for energy poverty risks

Embedding social safeguards ensures that climate ambition does not widen inequality.

(3) Institutionalize Political Economy Impact Assessments

Before implementing major climate reforms, governments should conduct structured political economy analyses to identify stakeholders, distributional impacts, and potential resistance coalitions.

APEC can support:

- Shared methodologies for political economy assessment
- Case-study exchanges on reform sequencing
- Stakeholder mapping tools
- Public perception monitoring frameworks

Proactive risk assessment improves policy durability and reduces reform reversals.

(4) Strengthen Regional Energy Security and Trade Dialogue

Carbon neutrality shifts geopolitical dynamics—particularly around critical minerals, energy imports, and carbon border measures. Without coordination, these shifts may escalate into trade tensions.

APEC should:

- Facilitate structured dialogue on CBAM impacts
- Promote mineral supply transparency mechanisms
- Encourage diversification strategies to reduce overdependence
- Support cooperative stockpiling and shared contingency planning regional coordination reduces competitive escalation and reinforces stability.

(5) Promote Public Communication and Climate Literacy

Public trust is essential for maintaining transition momentum. Misinformation, unclear cost-benefit narratives, or opaque decision-making undermine reform stability.

APEC should encourage:

- Climate literacy campaigns
- Evidence-based communication toolkits
- Public participation platforms
- Transparent disclosure of climate finance and carbon revenues Clear communication enhances legitimacy and reduces populist backlash.

(6) Enhance Macroeconomic Transition Planning

Large-scale electrification, infrastructure investment, and industrial transformation have macroeconomic implications—affecting inflation, trade balances, and employment patterns.

APEC should promote:

- Integration of climate targets into fiscal and monetary planning
- Scenario modeling of carbon pricing impacts
- Coordination between climate ministries and finance ministries
- Regional macroeconomic stress-testing of transition pathways

This ensures that decarbonization strengthens rather than destabilizes economic systems.

If effectively implemented, Theme 4 will enhance the political durability and macroeconomic stability of APEC's carbon neutrality transition. By managing energy pricing reforms, mitigating distributional impacts, and strengthening regional dialogue on trade and resource security, this theme reduces the risk of policy reversal, public backlash, and geopolitical tension. Political Economy and Transition Stability are not peripheral concerns; they determine whether climate ambition can be sustained over time. Effective governance in this domain ensures that decarbonization proceeds in a manner that is economically balanced, socially accepted, and resilient to external shocks.

5.2.5 Theme 5: Human Security & Just Transition

Carbon neutrality is not only an environmental target but a structural socio-economic transformation. Labor markets, public health systems, and generational expectations are directly affected by decarbonization policies. Without deliberate inclusion strategies, transition risks may disproportionately burden vulnerable workers, low-income households, and climate-exposed communities. Theme 5 therefore centers

on human security, workforce adaptation, and intergenerational legitimacy as foundational elements of a stable transition.

(1) Establish an APEC Green Skills and Workforce Transition Platform

The shift toward clean energy, electrification, hydrogen systems, and circular economy models will reconfigure labor demand across sectors. Workers in fossil fuel industries and carbon-intensive manufacturing face displacement risks, while demand for digital, electrical, and climate-related skills increases.

APEC should:

- Coordinate regional green skills taxonomies and certification standards
- Promote mutual recognition of climate-related professional qualifications
- Share training curricula for renewable energy, battery systems, and digital grid management
- Support public–private reskilling partnerships
- Encourage early mapping of at-risk occupations

This reduces structural unemployment and enhances workforce mobility across the region.

(2) Develop Anticipatory Labor Market Planning Mechanisms

Transition risks often materialize gradually but become socially destabilizing if unprepared. Governments should move from reactive compensation to anticipatory workforce planning.

APEC can promote:

- Sectoral transition roadmaps linking climate targets to labor demand projections
- Just transition funds targeting affected regions
- Early retirement or redeployment programs
- Regional peer learning on coal phase-out and industrial restructuring

Proactive planning minimizes social disruption and builds public confidence in reform processes.

(3) Strengthen Climate-Health Surveillance and Preparedness

Climate change increases risks of heat stress, vector-borne diseases, food-related illness, and water insecurity. These health impacts directly affect productivity and social stability.

APEC should encourage:

- Regional data-sharing platforms on climate-sensitive diseases
- Integrated health–climate monitoring systems
- Urban heat mitigation and public cooling infrastructure strategies
- Resilient healthcare infrastructure planning

Protecting public health enhances long-term economic resilience and human security.

(4) Institutionalize Youth Engagement and Intergenerational Dialogue

Generation Z and younger populations demonstrate strong climate awareness and expectations for structural change. Incorporating youth perspectives enhances policy legitimacy and innovation capacity.

APEC should:

- Create youth advisory mechanisms in climate policy dialogues

- Support regional innovation competitions and climate entrepreneurship programs
- Integrate sustainability literacy into education systems
- Facilitate cross-economy youth exchanges on climate solutions

Intergenerational inclusion strengthens democratic legitimacy and long-term commitment.

(5) Embed Equity and Inclusion Metrics into Climate Policy

Climate policies may unintentionally widen inequality if distributional effects are not measured and corrected. Just transition requires systematic evaluation.

APEC economies should:

- Incorporate gender and vulnerability impact assessments into climate legislation
- Track employment transition outcomes
- Monitor regional disparities in clean energy access
- Promote community participation in renewable and mining projects
- Develop benefit-sharing frameworks for local communities

Embedding equity metrics ensures fairness and reduces social fragmentation.

(6) Support Community-Level Resilience and Local Participation

Decarbonization projects—such as renewable energy installations, mineral extraction, or infrastructure expansion—directly affect local communities. Transparent governance and benefit-sharing mechanisms are essential.

APEC should promote:

- Participatory decision-making frameworks
- Community ownership models for renewable energy
- Local climate adaptation planning
- Conflict mediation mechanisms for resource-related disputes
- Local inclusion prevents social resistance and enhances project durability.

If effectively implemented, Theme 5 will enhance social resilience, protect vulnerable populations, and strengthen long-term public support for carbon neutrality across APEC economies. By investing in workforce reskilling, climate-health preparedness, youth engagement, and inclusive policy design, this theme reduces the risk of social fragmentation and transition-related inequality. Human Security and Just Transition are not complementary objectives but foundational conditions for durable decarbonization. Effective governance in this domain ensures that the transition toward net-zero emissions generates shared prosperity, intergenerational legitimacy, and sustained societal commitment.

6 Conclusions

The pursuit of carbon neutrality across the APEC region is both a global imperative and a uniquely complex structural transformation. As APEC economies collectively account for a dominant share of global greenhouse gas emissions and economic output, their transition pathways will decisively shape global climate outcomes. Yet carbon neutrality in the Asia-Pacific is not simply a technological shift; it requires coordinated transformation of governance systems, financial architectures, industrial production models, energy infrastructure, and social contracts.

This project—*Identification of Emerging Signals Affecting Carbon Neutrality in APEC Using Foresight*—has provided an integrated framework to understand how structural barriers, emerging signals, and adaptive policy responses interact in shaping decarbonization futures. By combining literature review, horizon scanning, survey validation, and participatory foresight workshops, the study established rigorous evidence base for anticipatory governance. Rather than forecasting a single future, the project strengthened regional capacity to identify weak signals, assess uncertainty, and prepare strategic responses under evolving conditions.

The review of structural challenges confirmed that APEC economies confront six interconnected barriers:

1) policy and governance gaps,
2) energy transition and technological lock-ins,
3) insufficient climate finance mobilization,
4) sectoral decarbonization hurdles in industry and transport,
5) equity and inclusion challenges in just transition processes, and
6) limited data, MRV, and institutional capacity.

These challenges are mutually reinforcing. Weak governance undermines investor confidence; insufficient MRV systems restrict transparency and access to climate finance; fossil infrastructure lock-ins slow innovation; and social resistance can destabilize reform processes. Carbon neutrality therefore requires systemic solutions rather than isolated policy interventions.

Through horizon scanning and expert validation, the project identified and prioritized emerging signals across seven challenge domains. High-priority signals include EV adoption mandates, smart grid scale-up, integrated MRV-data platforms, food insecurity, global water crisis, and worker reskilling programs. These signals demonstrate both high urgency and systemic impact. At the same time, frontier technologies—such as CCUS-as-a-service, thorium power plants, and lab-grown food—represent strategically important but uncertain signals requiring research, pilot programs, and regional knowledge exchange. Political economy signals, including energy pricing sensitivity and anti-carbon tax movements, highlight that societal acceptance and policy legitimacy are as decisive as technological readiness.

To translate foresight insights into structured action, the report developed a Policy Matrix framework**.** This framework operationalizes signal prioritization into five policy response categories:

- **Immediate Policy Action**: Signals requiring urgent intervention, including EV mandates, smart grid expansion, food and water security strategies, and integrated MRV platforms. Policy implications include mobilizing targeted

financing, accelerating regulatory reform, and strengthening regional coordination mechanisms.

- **Planned Deployment**: Emerging but credible pathways such as hydrogen economy development, carbon farming, battery recycling ecosystems, and nature-based bond frameworks. These require medium-term integration into economies' strategies, pilot scaling, and institutional capacity-building.
- **Risk Mitigation**: Signals associated with political economy volatility—such as energy affordability and anti-carbon tax movements—necessitate proactive social safeguards, transparent communication strategies, and compensatory mechanisms to maintain policy stability.
- **Strategic Preparedness**: Frontier innovations including CCUS-as-a-service, advanced nuclear technologies, and alternative protein systems. These demand investment in R&D, demonstration projects, regulatory readiness, and international collaboration.
- **Watchlist / Monitoring**: Weak signals not ready for deployment but warranting systematic observation to detect acceleration or disruption.

Building upon this framework, the report's policy recommendations emphasize three strategic directions:

1. **Strengthening Governance Architecture**: Establish legally durable climate frameworks, enhance institutional coordination, align regional standards, and upgrade APEC climate cooperation mechanisms to reduce fragmentation and improve policy coherence.
2. **Scaling Technology and Infrastructure Transformation**: Accelerate renewable integration, grid modernization, EV ecosystems, and circular economy systems, while addressing mineral security and supply chain resilience through regional collaboration.
3. **Mobilizing Finance and Ensuring Just Transition**: Expand transition finance instruments, improve climate risk disclosure, strengthen MRV systems to unlock investment, and prioritize worker reskilling and social protection to maintain public legitimacy.

Three overarching insights emerge for APEC:

- **Technology-driven transition is accelerating but uneven.** Rapid advances in renewable energy, electromobility, and digital platforms coexist with infrastructure bottlenecks and mineral dependencies, requiring anticipatory governance.
- **Nature and society resilience are prerequisites for long-term stability.** Food–water security, biodiversity protection, public health, and equitable workforce transition are inseparable from climate mitigation.
- **Enabling frameworks determine transformation speed.** Governance quality, transparent MRV systems, diversified finance, and harmonized regional standards ultimately shape the scale and credibility of decarbonization.

In conclusion, carbon neutrality in APEC is not solely an environmental target—it is a transformative development agenda. Achieving it requires balancing innovation with inclusivity, urgency with preparedness, and autonomy with regional cooperation. By institutionalizing foresight methodologies and embedding emerging signal analysis into policymaking processes, APEC can enhance its collective capacity to anticipate

disruptions, allocate resources strategically, and deliver a just, resilient, and timely transition toward carbon neutrality.

Through coordinated leadership and adaptive governance, the APEC region can position itself as a global leader in integrating science, technology, innovation, and inclusive policy to achieve sustainable prosperity for future generations.

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8 Appendix

8.1 APEC Survey on Emerging Signals for Carbon Neutrality

Carbon neutrality remains a challenging goal for APEC economies, requiring innovative policies and disruptive technologies. However, unexpected events can significantly accelerate or hinder progress toward these targets. To better prepare for such developments, APEC economies need to identify and monitor emerging signals—early indicators that could create substantial future changes.

This survey, which is part of the *APEC PPSTI project "PPSTI 211 2024A – Identification of Emerging Signals Affecting Carbon Neutrality in APEC using Foresight*", aims to gather expert insights on emerging signals in ***science, technology, and innovation*** that may impact carbon neutrality efforts across APEC economies. Your responses will help identify critical signals that warrant closer attention and inform policy recommendations for the region.

The survey should take ***approximately 15 minutes*** to complete. This survey automatically saves your progress, so you can return and complete it anytime if interrupted. ***Please complete the survey by September 22.***

Key questions

1. Please assess each signal by rating its Impact (1- 5)
2. Please assess each signal by rating its Likelihood to happen (1- 5)
3. How urgent of this signal in your economy? (1- 5)

Challenge area 1: Energy Transition and Technology

Signals reflect shifts in energy systems and technologies—such as renewables, storage, hydrogen, EVs, and grids—that are transforming pathways toward carbon neutrality.

1. **Corporate PPAs for clean power** - Corporations are signing long-term contracts for renewable energy to meet sustainability goals.
2. **Smart grid scale-up programs** - Smart grid technologies are scaling up to manage renewable energy fluctuations.
3. **Development of regional grid codes** - Standardized grid codes are enabling transboundary electricity trading.
4. **Battery reuse and second-life initiatives** - Reuse of EV and stationary batteries is gaining traction for distributed energy storage.

5. **Hydrogen diplomacy** - Bilateral agreements are shaping global green hydrogen trade routes.
6. **EV adoption mandates** - Mandates for EV sales shares or ICE phase-out dates are being legislated in several economies.
7. **Battery recycling and circular economy** - Increasing focus on end-of-life battery processing and recovery of rare metals.
8. **Microgrids** - Small-scale electricity distribution networks operating independently or with main grid.
9. **Energy Prosumerism** - Consumers who produce part of their electricity needs and inject surplus into grid.
10. **Massive Grid and Network Outage** - Large-scale malfunction shutting down electric grids and data networks.
11. **Hydrogen Economy** - Economic system where hydrogen replaces liquid fuels and serves as primary energy storage.
12. **CO2 Battery** - Rechargeable battery using carbon dioxide as cathode for energy storage.
13. **Algae Power** - Energy production utilizing algae in bioreactors for sustainable power generation.
14. **Ammonia Economy** - Economic system using synthetic green ammonia as carbon- free energy source.
15. **Renewable Energy Liquid** - Liquid carriers for storing renewable energy over long periods.

Challenge area 2: Environment and Natural Resources

Signals capture pressures and opportunities in ecosystems, land, water, and biodiversity, which influence resilience and carbon sinks in the face of climate change.

1. **Aquaculture and Blue Carbon Credits** - Marine farming combined with ocean carbon sequestration credits.
2. **Food Insecurity** - Growing mismatch between food demand and production/distribution capacity.
3. **Endangered Foods** - Crops and food varieties facing extinction due to climate change and biodiversity loss.
4. **Resource Wars** - Intensified struggles for control of scarce natural resources.
5. **Global Water Crisis** - Potential 40% shortfall in fresh water supply vs demand by 2030.
6. **Carbon Farming** - Agricultural practices transforming farms from carbon emitters to carbon sinks.
7. **Ocean as a Strong Carbon Sink** - Enhanced understanding and utilization of oceans' carbon absorption capacity.

Challenge area 3: Finance

1. **Climate risk guarantees** - Guarantees are being tested to crowd in private investment into clean energy and resilience.
2. **Transition bonds for high-carbon sectors** - Used to finance emission-reduction efforts in industries like steel, cement, and fossil transition.
3. **Nature-based bond frameworks** - Green bonds tied to forest, land, and biodiversity protection are gaining investor interest.
4. **Anti-carbon tax movements** - Fuel tax reforms have triggered public backlash in multiple APEC members.
5. **Carbon Trading and Carbon Credit** - Market mechanisms for trading carbon emissions allowances and offsets.
6. **Environmental & Pigouvian Taxes** - Taxes designed to discourage environmentally harmful activities.

Challenge area 4: Policy and Governance

Signals highlight regulatory frameworks, institutional reforms, and international cooperation that determine how climate commitments are implemented and enforced.

1. **Legal mechanisms for net-zero enforcement** - Governments are institutionalizing legal accountability mechanisms to ensure policy continuity.
2. **Long-term climate action plans with legal backing** - Climate action plans increasingly include multi-decade timelines and legal backing.
3. **Upgraded APEC climate mechanisms** - APEC is considering stronger cooperation platforms for technology and finance alignment.
4. **Accelerated ASEAN Power Grid deployment** - Grid interconnection is progressing slowly but gaining policy priority.
5. **Energy pricing as political trigger** - Energy affordability remains a politically sensitive issue in transitions.
6. **Border carbon adjustments** - Carbon import tariffs are being discussed to level the playing field on trade emissions.
7. **Regional climate data governance platforms** - New initiatives aim to harmonize MRV and emissions tracking across APEC economies.
8. **EU Taxonomy for Sustainable Activities** - Classification system defining environmentally sustainable economic activities.

Challenge area 5: Social and Just Transition

Signals represent social dynamics, workforce shifts, and equity concerns to ensure that the low-carbon transition is inclusive and fair across communities.

1. **Worker reskilling and transition programs** - Job training and relocation support is being scaled for fossil-sector workers.
2. **Generation Z Climate Perspectives** - Digital-native generation entering job markets with different climate perspectives.
3. **Hybridisation of Society** - Dynamic, adaptable and multidimensional transformation of social structures.
4. **Climate Change-Induced Diseases** - Spread of infectious diseases due to changing temperature and precipitation patterns.

Challenge area 6: Technology and Innovation

Signals stem from disruptive breakthroughs and applied innovations—from AI to advanced materials—that can accelerate or redefine decarbonisation strategies.

1. **Animal-Free Dairy Products** - Synthetic biology creating dairy products without using animals.
2. **Artificial Meat** - Synthetic products mimicking meat to reduce environmental impact.
3. **Lab-Grown Foods** - Food and beverage ingredients grown from animal and plant cells in laboratories.
4. **Precision & Robotic Agriculture** - Large-scale robotization and digitalization of farming operations.
5. **Regenerative Agriculture** - Holistic farming approach balancing ecological sustainability.
6. **EV Battery Revolution** - Development of alternatives to lithium-ion batteries for electric vehicles.
7. **Graphene Revolution** - Advanced material superior to current known materials in multiple properties.
8. **Zero-Emission Data Centres** - Data centers operating with renewable energy and carbon capture technology.
9. **Green AI** - Developing and deploying artificial intelligence systems that minimize energy consumption and environmental impact while maximizing efficiency.
10. **Small Nuclear Power Plants** - Safe, transportable small modular reactors for clean energy generation.
11. **Thorium Power Plants** - Nuclear power using thorium as alternative to traditional uranium.
12. **Mega-Infrastructure for Climate Adaptation** - Large-scale infrastructure projects for human adaptation to climate change.
13. **CO2 transport and storage infrastructure** - Dedicated CO2 pipelines and offshore storage sites are being developed to enable CCUS deployment
14. **CCUS-as-a-service** - Providing carbon capture, utilization, and storage capabilities as an outsourced service to businesses, eliminating their need to build and operate their own CCUS infrastructure.

Challenge area 7: Data & MRV

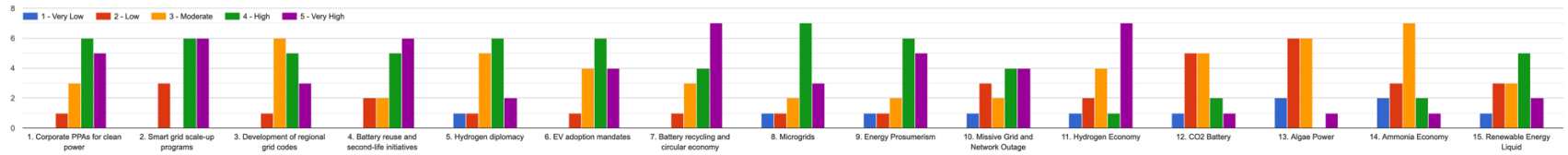
Signals relate to new data systems and MRV innovations that improve how emissions are tracked, verified, and linked with policy outcomes across economies.

1. **Integrated MRV-data platforms** – Economies are linking emissions inventories with policy outcome tracking systems.
2. **Peer learning and twinning programs** - Capacity-building initiatives pair advanced and emerging APEC members for mutual training.

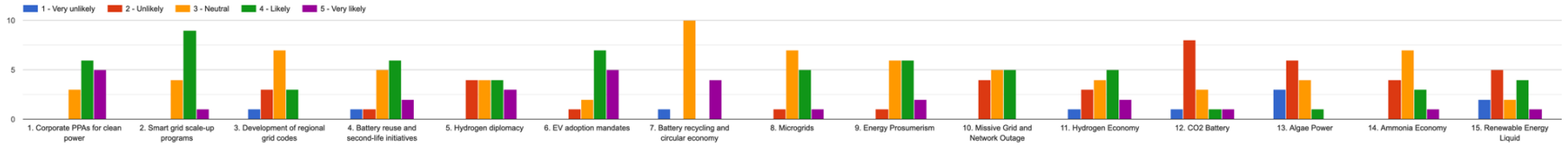
Survey results

Challenge area 1: Energy Transition and Technology

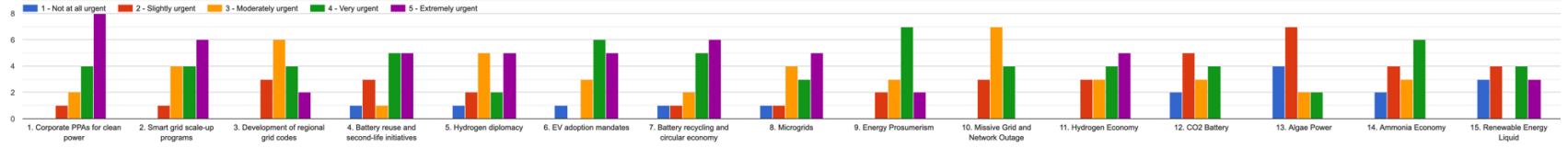
1. Please assess each signal by rating its Impact (1- 5)



2. Please assess each signal by rating its Likelihood to happen (1- 5)

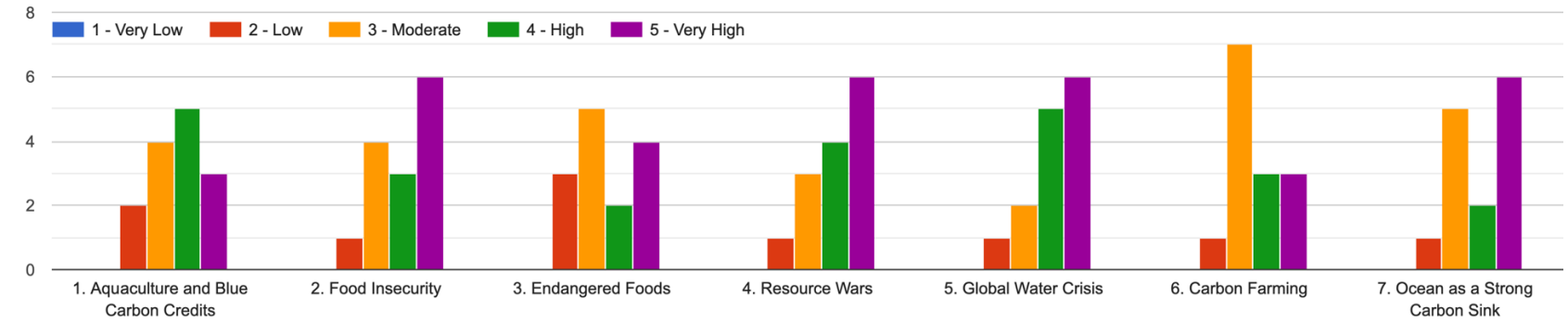


3. How urgent of this signal in your economy? (1- 5)

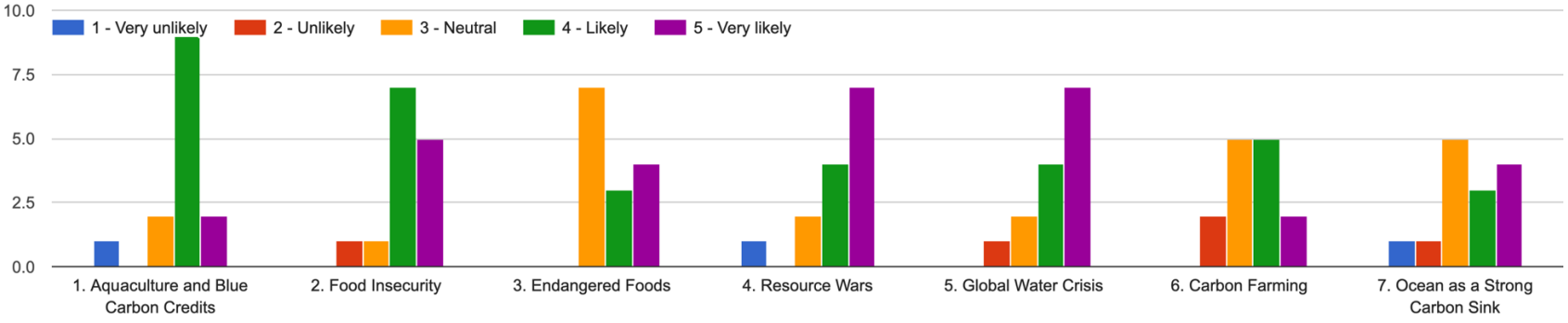


Challenge area 2: Environment and Natural Resources

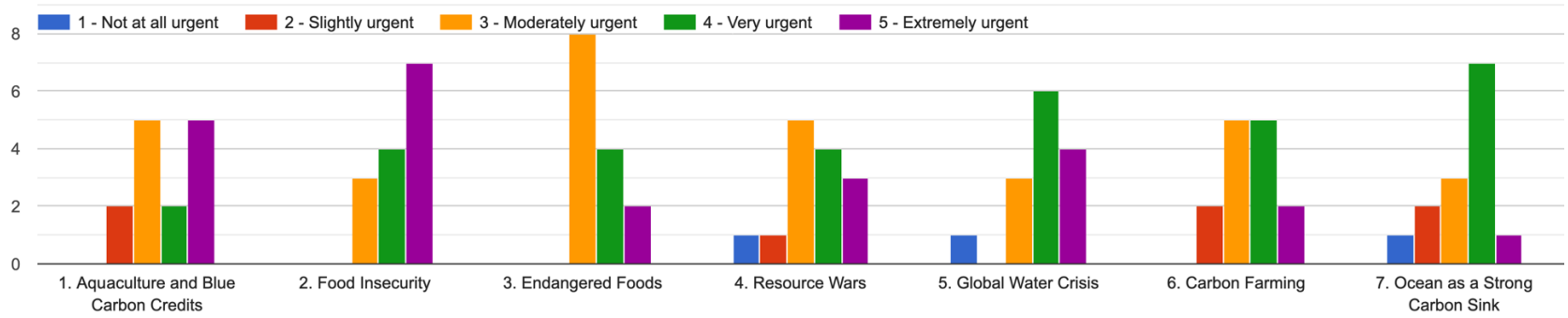
5. Please assess each signal by rating its Impact (1- 5)



6. Please assess each signal by rating its Likelihood to happen (1- 5)

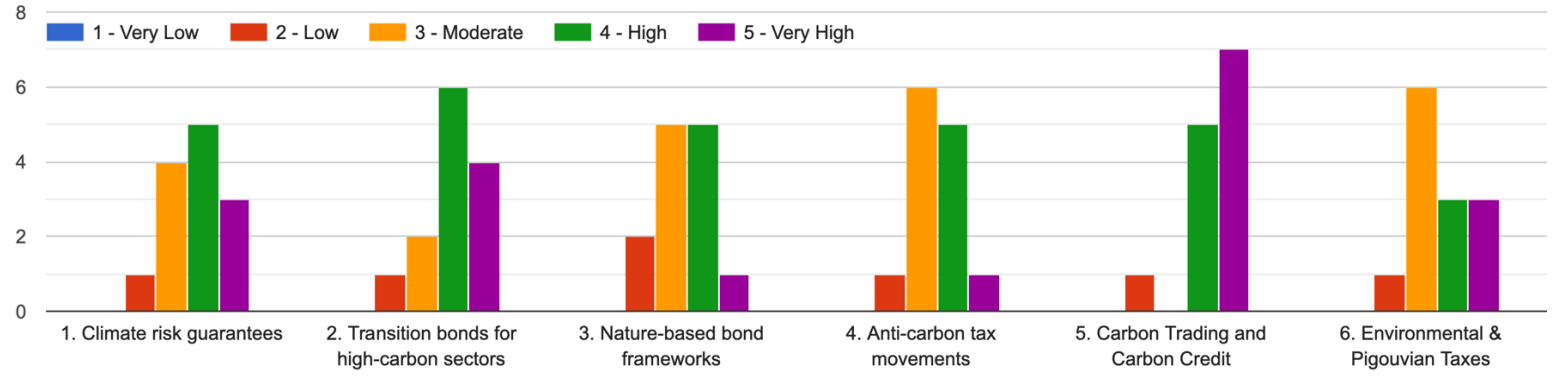


7. How urgent of this signal in your economy? (1- 5)

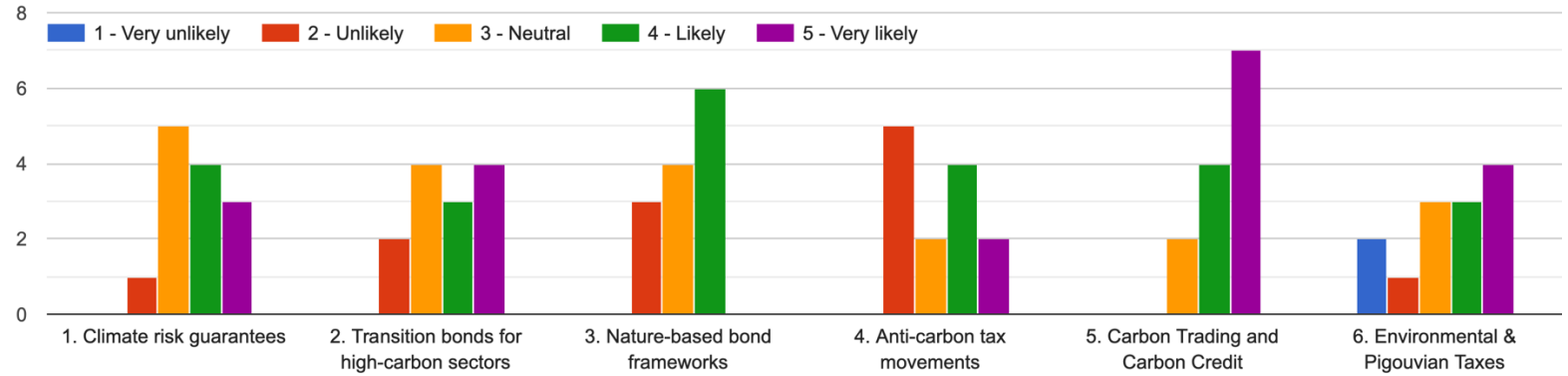


Challenge area 3: Finance

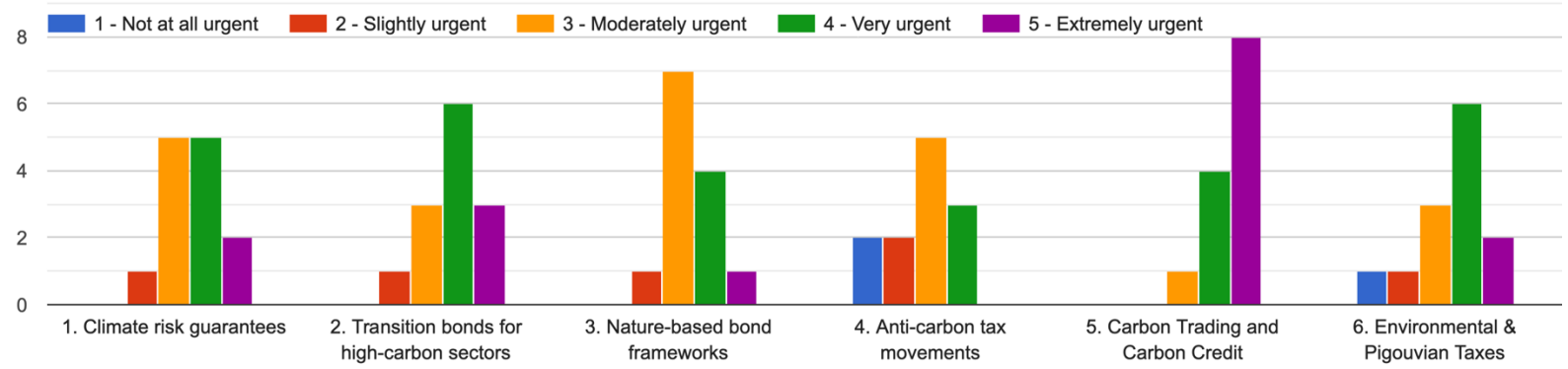
9. Please assess each signal by rating its Impact (1- 5)



10. Please assess each signal by rating its Likelihood to happen (1- 5)

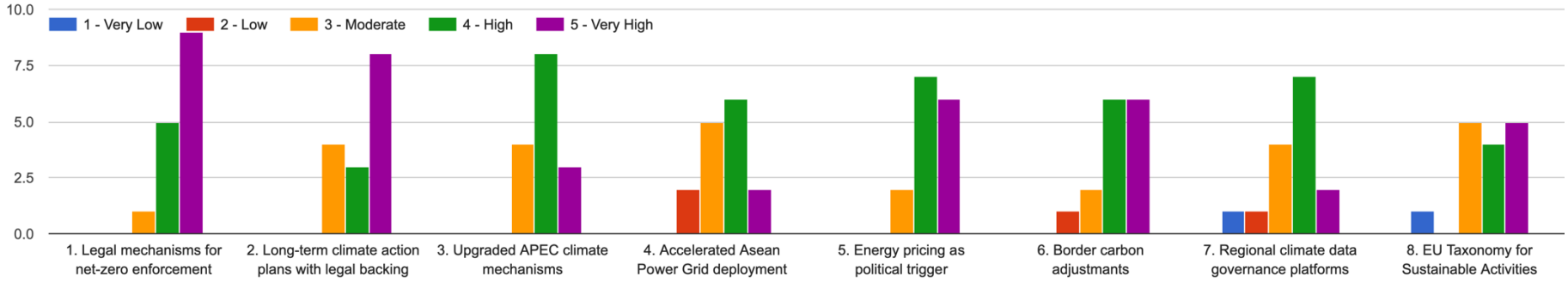


11. How urgent of this signal in your economy? (1- 5)

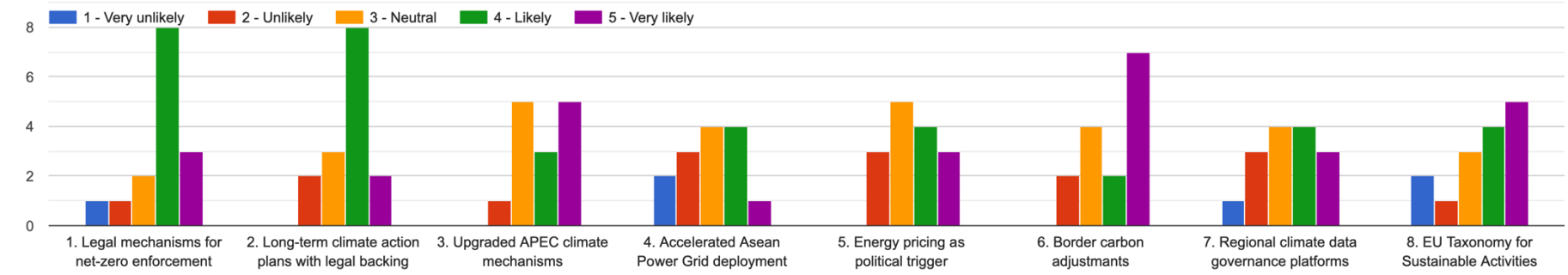


Challenge area 4: Policy and Governance

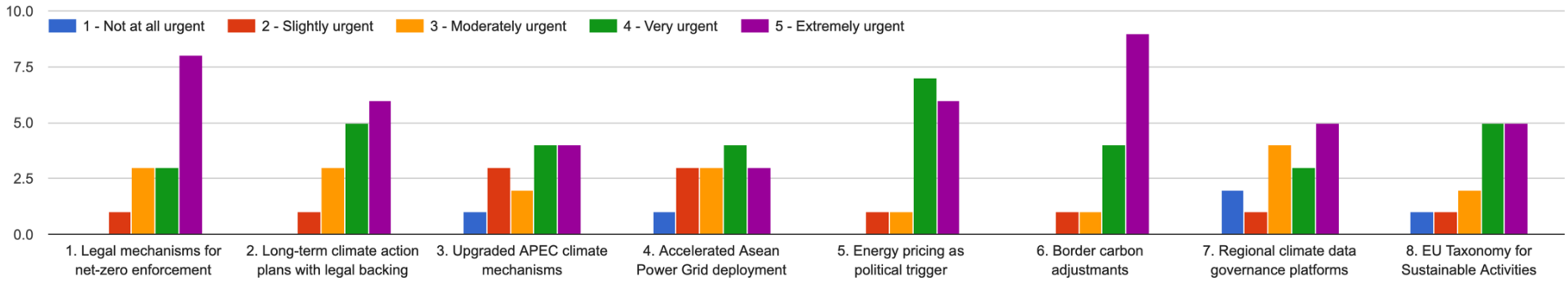
13. Please assess each signal by rating its Impact (1- 5)



14. Please assess each signal by rating its Likelihood to happen (1- 5)

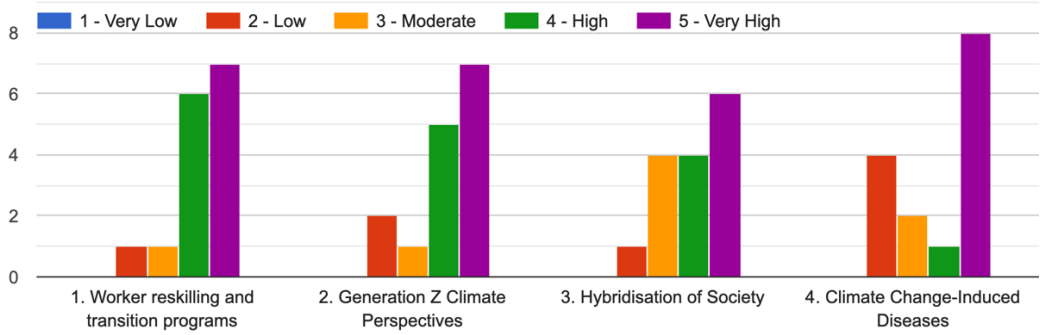


15. How urgent of this signal in your economy? (1- 5)

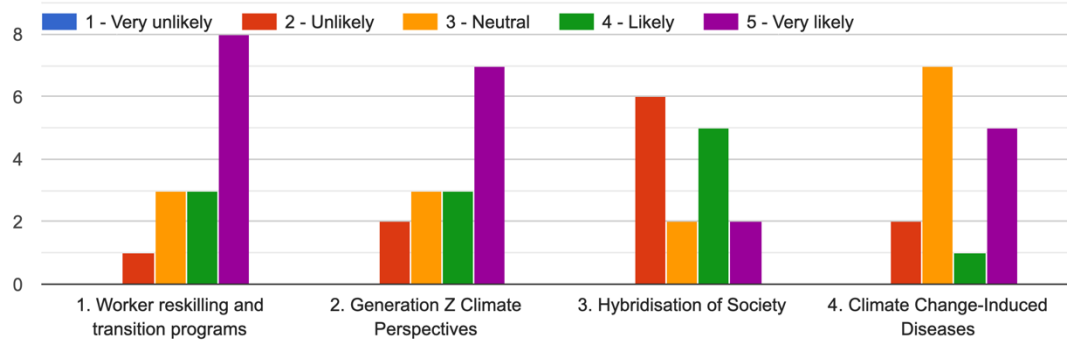


Challenge area 5: Social and Just Transition

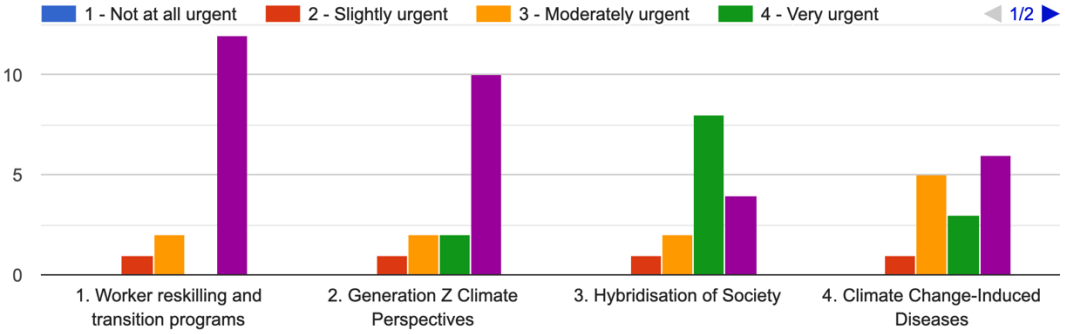
17. Please assess each signal by rating its Impact (1- 5)



18. Please assess each signal by rating its Likelihood to happen (1- 5)

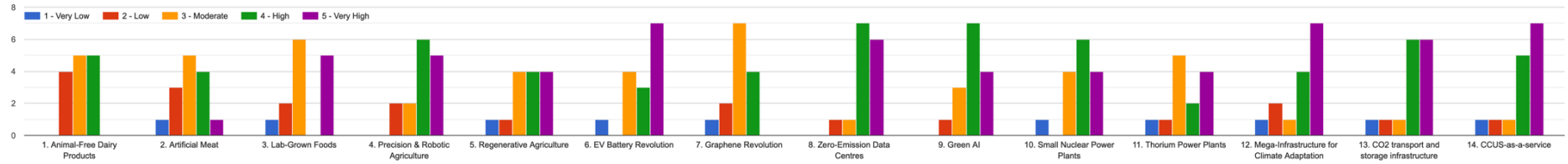


19. How urgent of this signal in your economy? (1- 5)

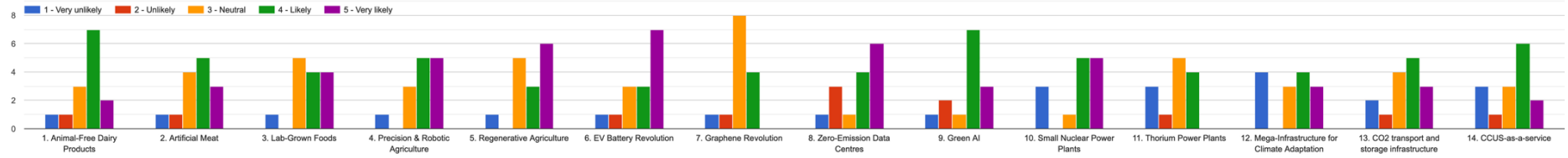


Challenge area 6: Technology and Innovation

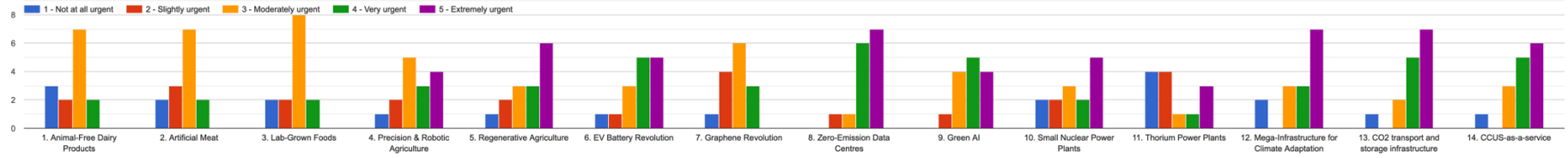
21. Please assess each signal by rating its Impact (1- 5)



22. Please assess each signal by rating its Likelihood to happen (1- 5)

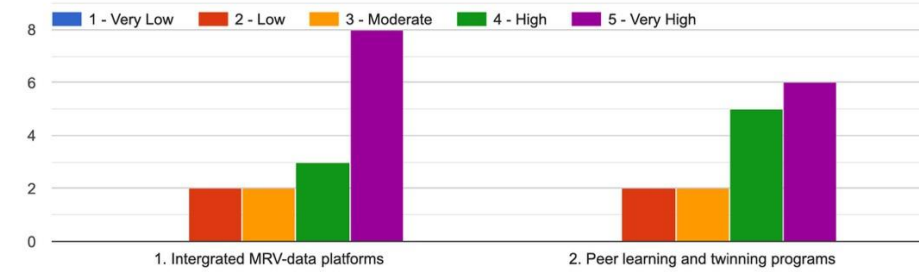


23. How urgent of this signal in your economy? (1- 5)

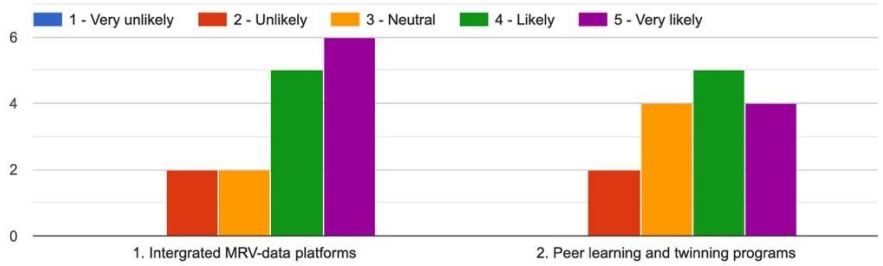


Challenge area 7: Data & MRV

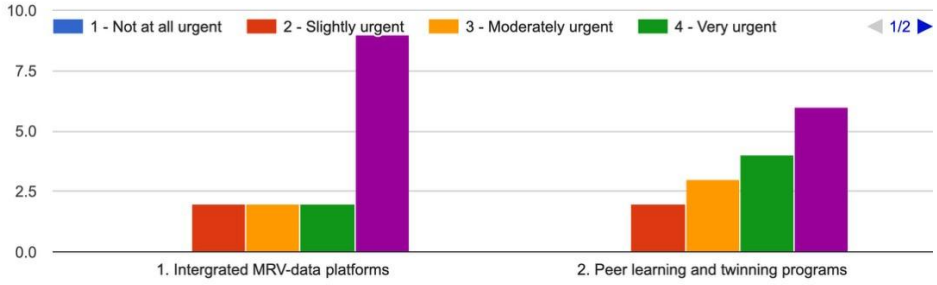
25. Please assess each signal by rating its Impact (1- 5)



26. Please assess each signal by rating its Likelihood to happen (1- 5)



27. How urgent of this signal in your economy? (1- 5)



8.2 APEC Foresight Workshop Activities

The **APEC Foresight Workshop on the Identification of Emerging Signals Affecting Carbon Neutrality** was held on **26–27 November 2025 in Bangkok, Thailand**, as part of the PPSTI project on strengthening foresight capacity for climate policy. The workshop was organized to support the **Asia-Pacific Economic Cooperation (APEC)** member economies in anticipating emerging developments that could either accelerate or hinder progress toward carbon neutrality, and to translate foresight insights into more proactive and coordinated policy responses.

The workshop aimed to enhance regional foresight capacity by enabling participants to:

- Validate and refine emerging signals affecting carbon neutrality across APEC economies
- Distinguish between weak signals, strengthening trends, and potential wild cards
- Identify priority signals requiring policy attention, strategic preparedness, or regional cooperation
- Co-create policy-relevant insights and recommendations for APEC PPSTI and member economies

The workshop emphasized participatory foresight as a tool for navigating uncertainty and supporting adaptive, forward-looking climate governance.

8.2.1 Workshop Agenda

APEC FORESIGHT WORKSHOP:
Identification of Emerging Signals Affecting Carbon Neutrality Using Foresight
26–27 November 2025 | Bangkok, Thailand

Day 1: Wednesday, 26 November 2025 - Classifying anticipatory signals

Time	Activity
08:30 – 09:00	Registration / Networking / Morning Coffee
09:00 – 09:10	**Opening Remarks:** **Dr. Surachai Sathitkunarat** President of NXPO Executive Director of APEC Center of Technology Foresight (APEC CTF)
09:10 – 09:30	Group Photo
09:30 – 10:00	**Foresight Warm-Up: Imagining Possible Futures with Cards** **Mr. Pawat Phongsai** Head of Research Team, Center for Futures Studies, NIA
10:00 – 10:30	**Keynote Speaker 1: "Towards Carbon Neutrality: Insights from the Australian Perspective and Opportunities for Regional Cooperation"**

Time	Activity
	Dr. Reza Aghdam – University of Sydney, Australia
10:30 – 10:45	Coffee & Tea Break
10:45 – 11.15	**Keynote Speaker 2: "Horizon Scanning and Trends Analysis"** **Dr. Tan Shu Ying** - Malaysian Industry-Government Group for High Technology (MIGHT)
11:15 – 12:00	**Workshop introduction & Methodology** - Preliminary results - Group walkthrough foresight radar - Rescanning the radar
12:00 – 13:30	Lunch Break
13:30 – 15:00	**Workshop Session 1: Signal Sensemaking & Classification** - Categorization (Weak, Wild Card, Emerging) - Impact & Uncertainty levels
15:00 – 15:15	Coffee Break
15:15 – 16:45	**Workshop Session 2: Signal Prioritization** - 10 critical signals selected for further development
16:45 – 17:00	Day 1 Wrap-up
18:00 – 19:00	Dinner

Day 2: Thursday, 27 November 2025 - Signals Prioritization & Co-creating strategy

Time	Activity
09:00 – 09:15	Day 1 Review & Findings
09:15 – 10:00	**Workshop Session 3: APEC's Co-creating future** - Benefits to APEC Member Economies - Opportunities for Strategic Collaboration
10:00 – 10:30	Coffee & Tea Break
10:30 – 11:30	**Workshop Session 4: Recommendation dialogue**
11:30 – 13:00	Lunch Break
13:00 – 17:00	**Panel discussion: Site visit NXPO – APEC CTF office** • Economy presentations (5 minutes each economy) • Potentially impactful signals
17:00 – 19:00	Closing Ceremony

8.2.2 Workshop Structure and Key Activities

Day 1: Signal Sensemaking and Prioritization

The first day focused on **collective sensemaking and analytical classification of emerging signals**. Participants were introduced to a foresight-based framework and a **Foresight Radar**, a visual tool used to map signals according to their potential impact and time horizon (near-term to long-term).
Building on a preliminary list of **56 emerging signals across nine thematic areas**, participants worked in groups to:

1. **Classify signals** into three categories:
    - **Weak signals**: early indicators of possible future change, characterized by uncertainty but high growth potential
    - **Strengthening signals**: developments already gaining traction, supported by evidence and early implementation
    - **Wild cards**: low-probability but high-impact events that could significantly disrupt socio-economic or technological systems
2. **Discuss implications and uncertainties**, including how different signals might interact with existing policy, technology, and social contexts in APEC economies.
3. **Prioritize signals**, narrowing the long list to approximately **ten critical signals** considered most relevant for deeper policy reflection and future-oriented analysis.

This process helped participants move beyond trend extrapolation and encouraged structured thinking about uncertainty, disruption, and preparedness.

Day 2: Co-Creating APEC Futures and Policy Implications

The second day shifted from analysis toward **collective reflection and co-creation**, focusing on how foresight insights can inform science, technology, and innovation (STI) strategies in APEC.
Key activities included:

- **Economy presentations**, where each participating economy delivered a concise presentation outlining:
    - Economies' carbon neutrality targets and policy directions
    - Emerging signals perceived as most impactful in their domestic context
    - Opportunities, risks, and strategic implications for achieving carbon neutrality
- **Panel discussions**, which explored cross-economy perspectives on shared challenges, divergent pathways, and opportunities for regional collaboration, particularly in areas such as energy transition, technology deployment, finance, governance, and data/MRV systems.
- **Collaborative dialogue on STI cooperation**, highlighting how science, technology, and innovation systems can support carbon neutrality through knowledge creation, technology diffusion, and innovation-led value creation.

The discussions emphasized that while economies' contexts differ, many emerging signals—such as EV mandates, smart grids, MRV platforms, climate finance

instruments, and just transition policies—have strong regional and cross-border dimensions that benefit from coordinated approaches.

8.2.3 Workshop Outcomes

The workshop produced a validated and prioritized set of emerging signals that are expected to shape carbon neutrality pathways across APEC economies, reflecting shared regional challenges as well as economy-specific contexts. Through collective foresight analysis, participants distinguished between signals requiring immediate policy attention, those suited for strategic preparedness, and those to be monitored over the longer term. The process enhanced mutual understanding of cross-cutting risks and opportunities—particularly in energy transition, technology deployment, governance, finance, social transition, and data/MRV systems—and highlighted signals with strong cross-border implications that would benefit from regional cooperation. In addition, the workshop strengthened foresight capacity among participating economies by demonstrating practical tools for managing uncertainty and integrating foresight insights into science, technology, and innovation (STI)–driven climate policy and long-term planning toward carbon neutrality.