Technology Foresight Scenarios and Policy Impact Assessment: Green Hydrogen

APEC Policy Partnership on Science, Technology and Innovation

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Asia-Pacific Economic Cooperation

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1. EXECUTIVE SUMMARY

This final report presents the findings of the *APEC Energy Transition Towards Net-Zero: Foresight Scenarios and Policy Impact (PPSTI 03 2024S)* conducted by the APEC Center for Technology Foresight (APEC CTF). The project examined foresight scenarios for hydrogen adoption across APEC economies with a focus on policy impacts to achieving carbon-neutrality.

The project assesses energy transition scenarios with a specific focus on hydrogen technologies across the APEC, examining three pathways: a Reference scenario (REF) that continues current policies and trends through 2050; a Carbon Neutrality scenario (CN) featuring slow adoption of hydrogen technologies available beyond 2030; and a Hydrogen Economy Policy scenario (HEP) presenting accelerated adoption with green hydrogen at scale by 2050.

The methodology employed integrates foresight processes with economic forecasting models. Our approach develops scenario logics by analyzing statistical trends and drivers, with primary data sourced from APEC Energy Demand and Supply Outlook 8th Edition by APEC Energy Research Centre (APERC 2022), and Perspective on hydrogen in the APEC region (APERC 2018). Following a comprehensive economic assessment (Muti-Regional Input Output: MRIO), we conducted the foresight workshop in Bangkok to create a foresight canvas that visualizes desired outcomes and pathways for Science, Technology, and Innovation (STI) collaboration across APEC economies.

Scenario 1: Reference (REF)

The REF scenario represents the continuation of current policies, existing trends in technology deployment, and socio-economic development to the year 2050. This baseline scenario reflects trends observed over the past decade without any major changes. Under this pathway, existing energy systems remain largely dominant, with limited penetration of hydrogen technologies and minimal policy intervention to accelerate energy transition efforts.

The REF scenario projects APEC hydrogen demand to increase by 166 Petra Joules (PJ) by 2050 (13% growth), with CO_2 emissions stabilizing with a slight 0.1% annual decline. It would require investment of approximately USD283 billion across APEC economies to 2050, with grey hydrogen remaining the dominant supply source (66% of investments).

Scenario 2: Carbon Neutrality (CN)

The CN scenario reflects a potential pathway where energy efficiency improvements, fuel switching initiatives, and technological advancements lead to a significant reduction in greenhouse gas emissions. Green and low-carbon hydrogen technologies become available in various sectors beyond 2030, but with relatively slow uptake and limited integration across the energy system. This represents a moderate approach to energy transition where hydrogen plays a supporting rather than central role.

The CN scenario projects hydrogen demand to increase by 241 PJ by 2050 (20% growth), with CO_2 emissions decreasing by 1.4% annually (30% reduction by 2050). It requires investment of approximately USD290 billion across APEC economies to 2050, with increased blue hydrogen adoption (26% of investments) and would create 9.3 million additional jobs across APEC economies.

Scenario 3: Hydrogen Economy Policy (HEP)

The HEP scenario investigates a hypothetical decarbonization pathway by advancing green and low-carbon hydrogen transition to attain carbon neutrality. This ambitious scenario assumes green hydrogen will be available at scale by 2050, supported by comprehensive policy frameworks, substantial investments in infrastructure, and coordinated regional collaboration. The HEP scenario positions hydrogen as a cornerstone of future energy systems across APEC economies.

The HEP scenario projects hydrogen demand to increase by 595 PJ by 2050 (48% growth from current demand), with CO_2 emissions decreasing by 2.0% annually (40% reduction by 2050). It requires investment of approximately USD326 billion across APEC economies to 2050, with a major shift toward green hydrogen investment. This scenario creates 30 million additional jobs (9 million directly in the hydrogen sector, 21 million in upstream/downstream sectors), with GDP growth USD327 billion larger than the REF scenario by 2050, and trade in hydrogen increasing by 26%.

Key Findings and Recommendations

Our analysis, based on modeling and the foresight workshop, suggests that the HEP scenario offers the most transformative pathway toward decarbonization. However, it requires significantly higher upfront investments and more ambitious policy coordination compared to the CN scenario. The REF scenario, while involving the lowest initial investment, results in higher long-term costs due to continued carbon lock-in and delayed technology adoption.

This project recommends the creation of standardized hydrogen policies across APEC economies to establish a borderless hydrogen market. Such a market would boost cross-border trade, accelerate technology adoption, and support sustainable economic growth. Additionally, social acceptance is identified as a key factor in the hydrogen transition, necessitating education, safety standards, and transparent communication to secure public and stakeholder support.

Implementing the recommended strategies is expected to deliver multiple benefits across APEC economies, including accelerated progress toward climate commitments, enhanced energy security through diversification of energy sources, the creation of high-value employment opportunities, strengthened regional economic integration, and technological leadership in a critical component of future global energy systems.

2. RATIONALE

Climate change and energy transition have emerged as central global challenges demanding urgent attention. As the world strives toward sustainability, reducing greenhouse gas (GHG) emissions and shifting away from fossil fuels have become critical objectives for governments, industries, and communities worldwide. The energy sector, responsible for a significant portion of global carbon emissions, plays a pivotal role in mitigating climate change impacts while simultaneously driving economic growth, job creation, and technological innovation (World Bank, 2021).

The Asia-Pacific Economic Cooperation (APEC) region holds exceptional significance in addressing these challenges, accounting for approximately 60% of global energy consumption and nearly 70% of global carbon dioxide emissions (APERC, 2022). The region's strategic importance is further underscored by its immense economic influence, representing 60% of global Gross Domestic Product (GDP) while housing 38% of the world's population. However, APEC contributes disproportionately to environmental impacts, generating 58% of global CO_2 emissions and 60% of global GHG emissions. This imbalance between population share and emissions footprint highlights both the responsibility and opportunity for APEC to lead global decarbonization efforts (IEA, 2023).

Emissions from APEC economies have grown at approximately 2% per annum from 2000 to 2021, significantly outpacing the 1.1% growth rate observed in non-APEC regions (IEA, 2023). The diverse economic landscape within APEC offers a unique platform for developing and implementing innovative solutions that can be adapted across different contexts and potentially replicated globally.

2.1 Trends and Drivers in Energy Transition

Based on investigations and signals from several sources of information such as policy reports from the IEA, APEC energy outlook studies, academic literature, and stakeholder consultations, the energy transition in the APEC region is shaped by multiple interrelated factors across the STEEP dimensions (Social, Technological, Economic, Environmental, and Political), as follow.

S: Social Factors

- **Energy Access**: Increasing efforts in decentralized renewable energy solutions and expansion of off-grid solar energy systems in remote and rural areas are improving energy access across the region.
- **Consumer Demand**: Growth in consumer interest towards electric vehicles (EVs) and sustainable technologies, alongside rising demand for home energy storage systems and energy-efficient appliances, is driving market transformation.

T: Technological Factors

- **Technological Innovations**: Accelerated adoption of solar and wind technologies, complemented by innovations in energy storage solutions like lithium-ion batteries and next-generation grid technologies, is creating new possibilities for clean energy systems.
- **Digitalization**: Growth of IoT and AI in energy systems for predictive maintenance and demand response, plus increased use of blockchain for

energy trading and decentralized energy management, is enhancing system efficiency and flexibility.

E: Economic Factors

- **Investments**: A surge in private and public investments into green bonds and renewable energy infrastructure, alongside increased funding for clean energy innovation and start-ups, is accelerating market development.
- **Green Jobs**: Rise in employment in the solar and wind industries, including manufacturing, maintenance, and research, complemented by growth in green collar jobs tied to sustainable technologies and energy efficiency services, is creating economic opportunities.

E: Environmental Factors

- **Climate Goals**: Increasing alignment of policies with global climate targets and growing focus on carbon capture and storage (CCS) and emission reduction technologies reflect strengthening environmental commitments.
- **Energy Security**: Diversification of energy sources, particularly increasing renewable penetration, coupled with investments in energy storage and grid modernization to support resilience in the face of climate impacts, is enhancing system sustainability.

P: Political/Policy Factors

- **Regulatory Support**: Introduction of carbon taxes and emissions trading schemes, alongside enactment of renewable energy mandates and incentives for cleaner technologies, is creating policy frameworks supportive of energy transition.
- **Global Trade**: Increase in international collaborations on clean energy technology sharing and material supply chains, supported by trade agreements favoring green technologies and sustainable energy investments, is facilitating global cooperation.

2.2 The Strategic Role of Hydrogen in APEC's Energy Transition

The APEC region is uniquely positioned to develop a robust hydrogen economy, with its abundant resources and diverse economic capabilities:

- **Production Potential**: Based on analysis from the APERC, the APEC region has sufficient resources to produce 7,840 billion Nm^3 of hydrogen annually using just 10% of available renewable energy resources. This far exceeds the projected regional demand of 1,367 billion Nm^3 by 2050.
- **Regional Complementarity**: Economies with abundant fossil fuel and renewable energy resources could emerge as hydrogen exporters, while economies with limited domestic production capacity would become importers, creating new trade relationships and economic opportunities.
- **Sectoral Applications**: By 2050, hydrogen could account for 3.7% of final energy consumption in industrial processes, 8.5% in the transport sector, and generate 3.4% of electricity across the APEC region.
- **Environmental Impact**: Full implementation of hydrogen across these sectors could reduce CO_2 emissions by approximately 1.2 Gt by 2050, equivalent to 6% of current emission levels in the APEC region.

Hydrogen emerges as a critical solution to address the limitations of current *energy transition strategies*, particularly in sectors where direct electrification remains technically challenging or economically unfeasible. As a versatile energy carrier, hydrogen offers several strategic advantages that align with the broader trends in energy transition:

- **Complement to Electrification**: While direct electrification is effective for many applications, hydrogen can address the remaining gaps, particularly in industrial heat processes, long-duration energy storage, and heavy transportation.
- **Industrial Decarbonization**: Hydrogen can replace fossil fuels in high-temperature industrial processes such as steel manufacturing and chemical production that constitute a significant portion of APEC's emissions.
- **Energy Storage Solution**: Hydrogen provides a pathway for long-duration and seasonal energy storage, addressing the intermittency challenges of renewable energy sources and enhancing grid stability.
- **Transportation Applications**: Fuel cell vehicles offer advantages in range, refueling time, and payload capacity compared to battery electric alternatives, particularly for heavy-duty transport, marine vessels, and potentially aviation.
- **System Integration**: Hydrogen facilitates the integration of diverse energy systems, connecting electricity, gas, transport, and industrial sectors in ways that enhance overall system efficiency and resilience.

The economic benefits of hydrogen deployment extend beyond emissions reduction. Studies suggest that *investments in hydrogen infrastructure* could create significant employment opportunities, with estimates indicating that green hydrogen investments generate more jobs per dollar invested than comparable fossil fuel projects (Jaeger et al., 2021). According to IRENA, renewable energy sectors employed over 11 million people globally in 2020, with significant increases in jobs related to solar, wind, and energy efficiency services (IRENA, 2020). For APEC economies seeking to balance economic growth with environmental sustainability, hydrogen presents a strategically important pathway.

Technological advancements are further accelerating the viability of hydrogen solutions. Similar to how solar photovoltaic costs have fallen by 89% over the past decade (IRENA, 2021), hydrogen production technologies are experiencing rapid cost reductions and efficiency improvements. These technological advancements, coupled with increasing investments in renewable energy infrastructure, are creating favorable conditions for scaled hydrogen deployment across the APEC region.

Regulatory frameworks are evolving to support hydrogen development, aligning with the broader policy trends identified earlier. Many APEC economies have introduced carbon pricing mechanisms, emissions trading schemes, and renewable energy mandates that indirectly benefit hydrogen technologies by penalizing carbon-intensive alternatives. For instance, the European Union Emissions Trading System has reduced emissions by 35% since its inception in 2005 (European Commission, 2021), demonstrating the effectiveness of such regulatory approaches that could be adopted or enhanced within APEC economies.

Regional cooperation through APEC mechanisms offers a unique opportunity to overcome the barriers to hydrogen adoption, including high production costs, technological challenges, and regulatory uncertainties. By facilitating knowledge sharing, technology transfer, and policy coordination, APEC can accelerate the development of a hydrogen economy across the region. The establishment of international standards and certification schemes for hydrogen would further enable cross-border trade and investment, creating new economic opportunities while advancing climate goals.

Furthermore, as outlined in the APEC Regional Trends Analysis report, APEC's capacity for energy transformation is further strengthened by the region's focus on policy alignment with global climate goals. With increasing investments in renewable energy and green technologies, APEC economies are well-positioned to lead the transition to a low-carbon future. Their commitment to carbon neutrality and the development of sustainable energy systems will not only foster regional resilience but also contribute to the global effort to achieve climate targets.

2.3 Hydrogen Outlook and Strategic Vision

The APERC Hydrogen Report 2023 and the APERC Perspective on hydrogen in the APEC region (2018) draw a future where low-carbon hydrogen plays a central role within APEC by 2035. This vision encompasses a landscape where hydrogen, produced with minimal carbon emissions, serves as a cornerstone of energy systems across the region. Key driving forces and trends also identified in the APEC STI Strategic Foresight: Net Zero Emissions/ Carbon Neutrality Report (2024) include:

- Hydrogen's critical role in decarbonizing hard-to-abate sectors within APEC economies
- Its ability to enable deep decarbonization in industries and complement sectors such as heavy transportation
- The enhancement of energy system stability through seasonal storage capabilities
- The essential role of green hydrogen for hard-to-reduce industries to achieve zero-carbon production
- Rapid growth and technological advancements in the hydrogen industry

2.4 Categorization of APEC Economies in Hydrogen Development

Given the critical importance of the hydrogen economy in achieving APEC's climate and energy transition goals, this project undertakes a comprehensive review and analysis of hydrogen policies across all member economies. To better understand the diverse landscape of hydrogen development within the region and to facilitate targeted policy recommendations, this study systematically examines each economy's hydrogen strategies, resource endowments, and implementation capabilities.

The heterogeneous nature of APEC economies - ranging from resource-rich economies with vast export potential to import-dependent economies with specific sectoral applications - necessitates a differentiated approach to hydrogen policy analysis. Therefore, this project groups the 21 APEC economies into three distinct categories based on their hydrogen development trajectories, which will serve as the foundation for scenario modeling and policy impact assessment in subsequent chapters.

The following table summarizes the classification of APEC economies into these three distinct hydrogen development groups applied in this project.

Table 1: Summary of categorization of APEC economies in hydrogen development applied in this project

	Group 1: Net-exporting economies	Group 2: Producing economies	Group 3: Non-producing economies
Production Scale	Large-scale production aimed at exports	Significant production focused on domestic use	Limited production, reliant on imports
Policy Focus	Infrastructure development, cost reduction, international trade	Infrastructure, domestic use promotion, integration with renewables	Strategic roadmaps, pilot projects, niche applications
Investment Levels	High public and private investments in hydrogen projects and R&D	Significant investments in R&D and technological improvements	Initial investments, focusing on feasibility and pilot projects
Economic Impact	Substantial contributions to GDP and job creation through exports	Enhancing energy security, reducing emissions, domestic job creation	Improving energy efficiency, reducing emissions, sector-specific integration
Technological Advancement	High focus on innovation and R&D	Emphasis on innovation, technological improvements	Initial phases, focusing on feasibility and pilot projects
Infrastructure Development	Comprehensive networks for production, storage, transport, refueling	Developing domestic infrastructure across multiple sectors	Initial phases of infrastructure development
International Collaboration	Strong focus on international trade and partnerships	Partnerships for technological advancements and best practices	Developing partnerships and strategic alliances

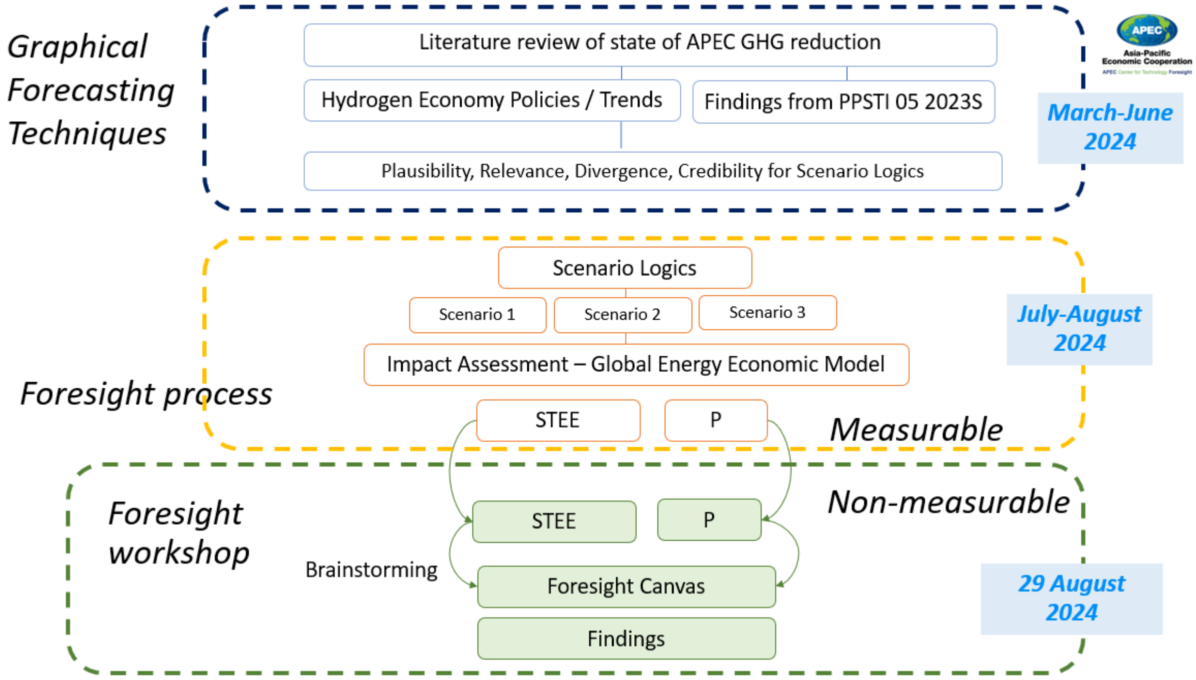
The first group consists of potentially net-exporting economies with large-scale production capabilities and export ambitions. The second group focuses primarily on domestic production to meet internal demand while building comprehensive infrastructure. The third group relies on imports due to limited domestic production capacity, concentrating on strategic development and pilot initiatives.

These groupings reflect varying approaches to hydrogen development, influenced by natural resource endowments, energy security considerations, and economic development strategies. Each group faces unique challenges and opportunities in their hydrogen journey, from scaling production and building infrastructure to integrating hydrogen across multiple sectors and reducing costs. The policies implemented by these economies are shaped by eight key factors that drive hydrogen development across the region, including production expansion, infrastructure development, sectoral integration, energy reliability, technological advancement, emissions reduction, cost competitiveness, and international collaboration.

3. METHODOLOGY

This project employed a comprehensive methodological approach combining forecasting techniques with foresight tools to assess energy transition scenarios in the APEC region, with particular focus on low-carbon hydrogen adoption. The methodology consisted of interconnected components that together provided both quantitative assessment and qualitative strategic insights to inform policy recommendations.

Figure 1: Project methodological framework



3.1 Scenario Development

This project develops three scenarios that represent alternative futures for the hydrogen economy in APEC up to the year 2050, namely, Reference (REF), Carbon Neutrality (CN), and Hydrogen Economy Policy (HEP). The first two scenarios are broadly aligned with the APEC's Energy Demand and Supply Outlook (APERC, 2022), where hydrogen will play a minimal-to-moderate role in APEC's energy mix, whereas the third scenario will focus on the accelerated adoption and full integration of hydrogen in APEC economies.

The REF scenario is designed to broadly represent the continuation of current policies, existing trends in technology deployment and socio-economic development, to the year 2050. In particular, it reflects trends observed over the past decade, without any major changes taking place. For example, energy efficiency is assumed to improve gradually, electrification continues to gather pace, fuel switching from coal to gas continues, and the adoption of renewable energy accelerates (APERC, 2022).

The CN scenario reflects a potential pathway where energy efficiency, fuel switching, and technological advancement lead to a significant reduction in greenhouse gas emissions. The carbon-neutrality in this project refers to refers to the contribution of emissions reduction from the energy sector only, primarily from fossil fuel combustion in various economic activities. Sources of other emissions, such as from 17 changes in land-use, and industrial and agricultural processes, are not considered. In terms of hydrogen, green and low-carbon (blue) hydrogen is assumed to be available in various end-use sectors, particularly industry, transport and buildings, beyond 2030 (APERC, 2022).

The HEP scenario further investigates a hypothetical decarbonization pathway for the energy sector by advancing green and blue hydrogen transition. That is, hydrogen energy is assumed to be available at a scale to the accelerated use of hydrogen in industry, transport and buildings, hydrogen use by the power sector (as a storage option) will also be considered in the HEP scenario.

The impact assessment framework for this report is centered on the development and application of an energy-focused Multi-Regional Input-Output (MRIO) model. The regional grouping in this model comprises three groups for APEC economies (as outlined in Table 1) and a single group for non-APEC economies.

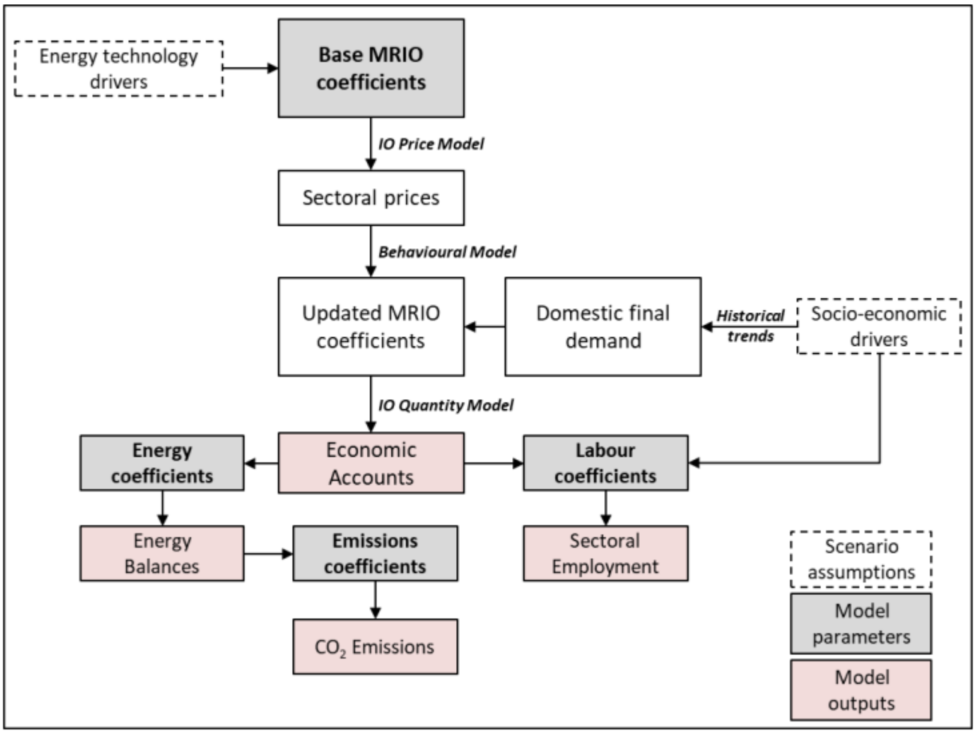
The model developed for this study represents a variation of environmentally-extended Input-Output analysis, specifically designed to capture energy balances within and across the four regional groupings. Furthermore, this model is a modified version of the traditional Leontief IO model, where the assumption of fixed technical coefficients is relaxed by treating these coefficients as functions of relative input prices. This modification enables price-responsive behavior in production and consumption decision-making processes.

The methodology employs Global Trade Analysis Project (GTAP) data as its foundation, providing forecasting capabilities for comprehensive STEEP impact assessment to compare policy impact options across different scenarios. The energy-economic model facilitates the integration of both economic forecasting and foresight techniques, enabling holistic evaluation of potential future outcomes.

Key features of the model include detailed representation of physical and monetary accounts, comprehensive mapping of intersectoral and interregional dependencies, and price-driven substitution mechanisms among inputs and products. These integral aspects allow the model to capture complex economic interactions and provide robust analytical capabilities for policy impact assessment.

The overall analytical framework for the model is illustrated in Figure 2, demonstrating the interconnected nature of the various components and their role in generating comprehensive impact assessments across the different regional groupings and policy scenarios.

Figure 2: Analytical framework



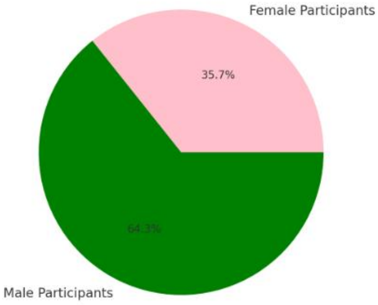
3.2 Foresight Workshop and Canvas Development

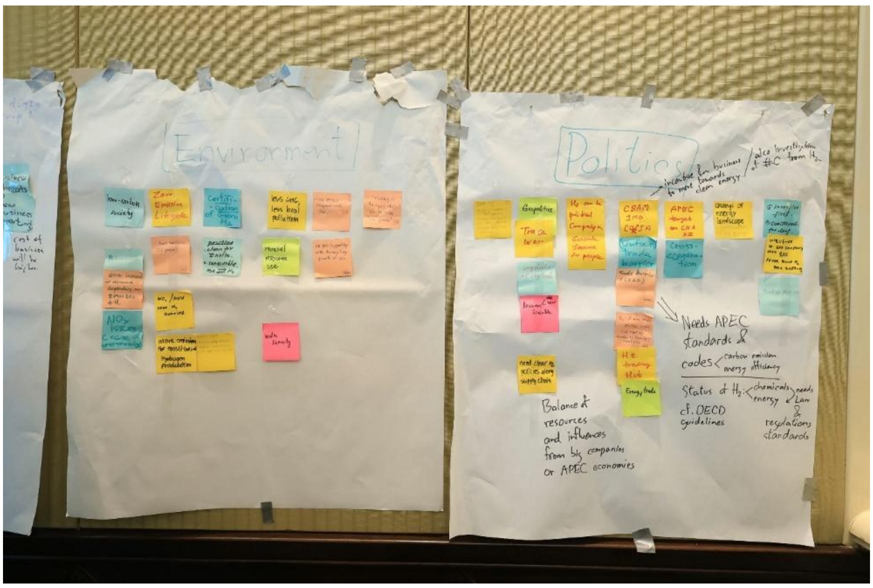
The methodology incorporated participatory foresight techniques through a dedicated workshop titled "Technology Foresight Scenarios Towards Net-zero Emission and Policy Impact Assessment," themed "Green Horizon: Towards a Hydrogen Economy." The workshop was held from 28-30 August 2024, at Sofitel Krabi Phokeethra Golf & Spa Resort in Krabi, Thailand. It aimed to build capacity in foresight methodology, illustrate energy transition scenarios in APEC, focus on the hydrogen economy to foster STI collaboration, and address energy transition barriers.

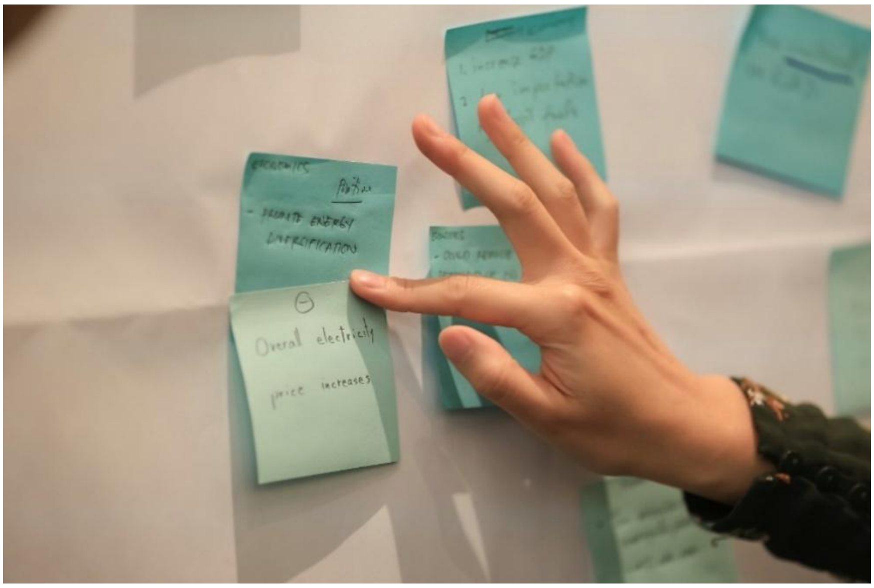
The three-day workshop included sessions on foresight activities, panel discussions, site visits, and networking opportunities with leading experts, ensuring that diverse perspectives were incorporated into the scenario development and policy recommendations through this collaborative approach. The workshop successfully brought together 42 participants (15 female and 27 male attendees) representing seven APEC economies – Brunei Darussalam; Malaysia; Peru; the Philippines; Russia; Chinese Taipei; and Thailand.

Participants gained valuable insights into cutting-edge developments in the APEC hydrogen economy while building capacity in foresight methodology using STEEP and Foresight Canvas approaches. The workshop achieved its expected outcomes by successfully developing strategic recommendations for APEC's low-carbon hydrogen integration and establishing a foundation for STI collaboration to support APEC's carbon neutrality goals.

Figure 3: Summary of workshop participants







During the workshop, participants engaged in:

- STEEP analysis to identify both measurable and non-measurable indicators
- Integration of quantitative results with qualitative expert insights
- Development of a Foresight Canvas to visualize future possibilities

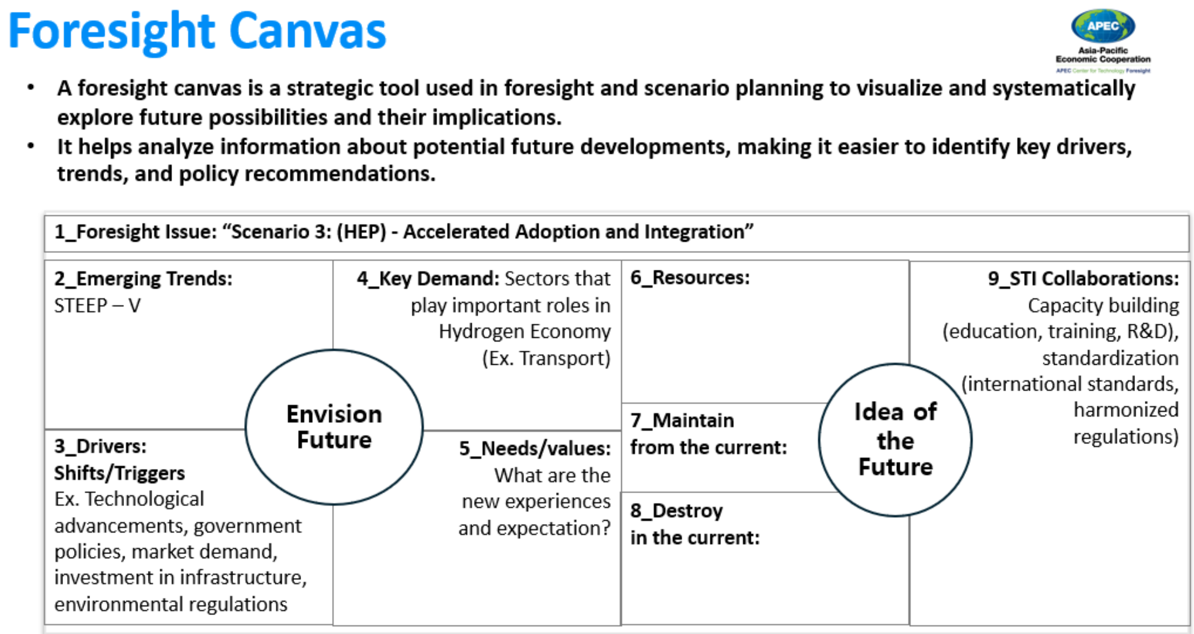
The STEEP framework was employed to ensure comprehensive assessment across multiple dimensions:

- Social: Job creation, community resilience, public acceptance of hydrogen technologies
- Technological: Hydrogen production and demand patterns, innovation rates, technology transfer effectiveness
- Economic: GDP impacts, market development, economic stability, impacts on traditional energy markets
- Environmental: CO_2 emission reductions, renewable energy adoption, ecosystem health
- Political: Trade patterns, international collaboration, regulatory frameworks

The Foresight Canvas served as a strategic tool to:

- Define the foresight issue ("Accelerated Adoption and Integration" under the HEP scenario)
- Document emerging trends across STEEP dimensions
- Identify key drivers and triggers for hydrogen adoption
- Analyze sectoral demands and resource requirements
- Highlight needs, values, and expectations for the future hydrogen economy
- Determine what should be maintained and what should be transformed from current systems
- Outline STI collaboration opportunities within APEC

Figure 4: Foresight Canvas framework



The combination of quantitative forecasting and qualitative foresight tools builds a major methodological advancement that overcomes the constraints inherent in using either approach independently. This integrated methodology delivered multiple advantages, as follow:

- ***Addressing Uncertainty Beyond Quantifiable Parameters***

  While the economic modeling provided robust projections of measurable indicators like GDP growth and emission reductions, the foresight tools allowed exploration of critical uncertainties that resist quantification—such as social acceptance, political will, and technological breakthroughs. By incorporating these non-measurable factors, the methodology provided a more holistic understanding of potential futures.

- ***Bridging Technical Analysis and Strategic Vision***

  The forecasting models delivered detailed technical analysis of hydrogen adoption pathways, but the foresight process transformed these technical insights into strategic vision. The Foresight Canvas specifically enabled stakeholders to envision desirable futures and identify concrete actions required to realize them, moving beyond what is probable to what is possible and preferable.

- ***Facilitating Multi-Stakeholder Engagement and Consensus***

  The participatory nature of the foresight workshop brought together diverse stakeholders from across APEC economies, fostering shared understanding and consensus on priorities. This participatory approach enhanced the legitimacy of findings and increased the likelihood of coordinated action across economies.

- ***Revealing Non-Linear Relationships and Emergent Phenomena***

  While economic models excel at projecting linear trends, the foresight process helped identify potential tipping points, emergent phenomena, and transformative opportunities that might otherwise remain hidden. This was particularly valuable in exploring the transformative potential of the HEP scenario.

- ***Translating Complex Data into Actionable Insights***

  The Foresight Canvas served as a powerful tool for distilling complex modeling results into accessible, actionable insights for policymakers. By visually mapping relationships between current actions and future outcomes, the canvas made the pathway to hydrogen economy tangible and navigable.

4. IMPACT ASSESSMENTS

This section presents an analysis of three scenarios. Each scenario represents fundamentally different pathways for hydrogen economy development, reflecting varying levels of policy ambition, technological advancement, and other concerns related to the scenarios.

4.1 Comparative Analysis of Scenario Characteristics

The three scenarios represent pathways for hydrogen economy development in the APEC region. The REF scenario maintains current trends with limited hydrogen production, minimal infrastructure, and fragmented policies. The CN scenario introduces moderate hydrogen deployment focused on selected sectors with partially coordinated policies. The HEP scenario envisions extensive hydrogen adoption across all sectors, comprehensive infrastructure development, and highly coordinated regional collaboration. These scenarios progress from minimal hydrogen integration to transformative economy-wide adoption, as summarized in the following table.

Table 2: Summary of categorization of APEC economies in hydrogen development

Characteristic	REF	CN	HEP
Hydrogen Production Scale	Limited	Moderate	Extensive
Supply Mix (2050)	75% Grey 20% Blue 5% Green	40% Grey 40% Blue 20% Green	10% Grey 30% Blue 60% Green
Infrastructure Development	Minimal	Focused	Comprehensive
Sectoral Integration	Existing applications	Selected hard-to-abate sectors	Widespread across economy
International Trade	Limited	Moderate	Extensive
Policy Coordination	Fragmented	Partially coordinated	Highly coordinated
Investment Level	Low	Medium	High
Innovation Focus	Incremental	Significant	Transformative
APEC Collaboration Level	Limited	Moderate	High

Characteristic	REF	CN	HEP
Technology Transfer	Minimal	Selective	Comprehensive
Economic Benefits	Limited	Moderate	Maximum
Environmental Impact	Minimal improvement	Significant improvement	Transformative improvement

REF Scenario: Fragmented Regional Development

Under the REF scenario, APEC economies pursue largely independent paths in hydrogen development, resulting in:

- Duplication of efforts across economies
- Limited economies of scale
- Slower technology cost reductions
- Incompatible standards and regulations
- Minimal leveraging of complementary resources
- Persistence of technology gaps between developed and developing economies

CN Scenario: Emerging Regional Cooperation

The CN scenario features increasing but limited regional cooperation, characterized by:

- Growing bilateral and sub-regional partnerships
- Progressive alignment of technical standards
- Selective technology transfer
- Modest regional hydrogen trade
- Partial utilization of complementary resources
- Reduced but persistent technology gaps

HEP Scenario: Integrated Regional Approach

The HEP scenario envisions a comprehensive regional approach to hydrogen development, featuring:

- Coordinated regional hydrogen strategy
- Fully integrated hydrogen market
- Harmonized standards and regulations
- Accelerated technology diffusion across economies
- Optimized utilization of regional resources
- Substantial reduction in technology gaps
- Establishment of APEC as a global hydrogen leader

4.2 Expected Implementation and Supply Projections

The scenarios included detailed projections of hydrogen supply by type (green, blue, and grey) through 2050.

4.2.1 Global Hydrogen Supply Projections

- **REF Scenario**: Limited growth in green hydrogen, with grey hydrogen still playing a significant role by 2050. Grey hydrogen remains dominant (75% by 2050), with limited blue hydrogen (20%) and minimal green hydrogen (5%).
- **CN Scenario**: Increased adoption of blue hydrogen, with moderate growth in green hydrogen. Declining grey hydrogen (40% by 2050), increasing blue hydrogen (40%), and growing green hydrogen (20%).
- **HEP Scenario**: The most aggressive transition to green hydrogen, with grey hydrogen being almost entirely phased out by 2050. Rapid decline in grey hydrogen (10% by 2050), substantial but transitional blue hydrogen (30%), and dominant green hydrogen (60%).

In terms of global hydrogen energy supply projections to 2050:

- Green hydrogen increases from less than 10% to over 70% of supply in the HEP scenario
- Blue hydrogen reaches approximately 25% in the HEP scenario
- Grey hydrogen reduces from over 70% to less than 5% in the HEP scenario

The HEP scenario represents the most significant shift towards Green hydrogen, with Grey hydrogen being almost entirely phased out by 2050. In contrast, the REF and CN scenarios show more modest shifts, with Grey hydrogen still playing a significant role and Green hydrogen making slower gains.

4.2.2 Implementation Trajectories by Economy Group

The implementation of hydrogen technologies varies significantly across the three economy groups under each scenario:

Group 1: Net-exporting Economies

- Under HEP: Rapid scaling of green hydrogen production for both domestic use and exports
- Under CN: Moderate expansion with focus on blue hydrogen
- Under REF: Limited expansion primarily serving existing industrial applications

Group 2: Producing Economies

- Under HEP: Substantial domestic production focused on self-sufficiency and industrial applications
- Under CN: Moderate production growth serving primarily domestic needs
- Under REF: Incremental growth with limited sectoral expansion

Group 3: Non-producing Economies

- Under HEP: Development of niche production capabilities and import infrastructure
- Under CN: Limited domestic production with growing import capacity

- Under REF: Minimal hydrogen infrastructure development

The analysis showed significant differences in implementation trajectories between the scenarios, with the HEP scenario demonstrating faster adoption rates and more widespread implementation of hydrogen technologies by 2050.

4.3 STEEP Framework Analysis Methodology

The policy impact assessment utilized a STEEP (Social, Technological, Economic, Environmental, Political) framework to evaluate the comprehensive effects of different hydrogen implementation scenarios across APEC economies.

4.3.1 Social Impact Assessment

The social impact analysis encompasses both quantifiable employment effects and broader societal changes across the three hydrogen development scenarios. Employment in hydrogen-related sectors shows substantial growth potential, from the current 2.5 million jobs globally to projections ranging from 5.2 million under the Reference scenario to 30 million additional jobs under the ambitious HEP scenario. Beyond employment metrics, critical non-measurable social dimensions include public acceptance of hydrogen technologies, community resilience through distributed energy systems, quality of life improvements from reduced pollution, and safety perceptions that influence adoption rates. The analysis reveals that more ambitious scenarios require increasingly robust community engagement and education strategies to achieve successful implementation.

Table 3: Summary of social impact assessment

Social Category	Baseline (2023)	REF (2050)	CN (2050)	HEP (2050)
Employment (Hydrogen Sector)	2.5 million jobs globally	5.2 million jobs	9.3 million additional jobs	30 million additional jobs
Direct vs. Indirect Jobs	Current baseline	Limited expansion	Moderate expansion	9M direct, 21M indirect
Social Acceptance Requirements	-	Minimal engagement	Moderate programs	Extensive strategies needed
Community Resilience	Current levels	Limited improvement	Moderate enhancement	Significant transformation
Quality of Life Impact	Baseline conditions	Minimal air quality gains	Notable pollution reduction	Transformative improvements
Public Safety Concerns	Low awareness	Limited deployment issues	Moderate safety awareness	High education requirements

Social Category	Baseline (2023)	REF (2050)	CN (2050)	HEP (2050)
Community Engagement Needs		Basic information sharing	Targeted education programs	Robust multi-stakeholder approach

Quantitative Model Results The modeling analysis demonstrates substantial employment growth potential across all hydrogen development scenarios, with current global hydrogen sector employment of 2.5 million projected to reach 5.2 million under the Reference scenario, 9.3 million additional jobs under the Carbon Neutrality scenario, and an ambitious 30 million additional jobs under the HEP scenario by 2050. The most dramatic growth occurs in Group 1 and Group 2 economies, with employment increases ranging from 91-128% in conservative scenarios to 743-788% under aggressive hydrogen adoption, indicating significant potential for economic development and household income improvements across the APEC region.

Workshop Foresight Insights The foresight workshop identified critical social dimensions that extend beyond employment metrics, emphasizing the interconnected nature of social acceptance, human capital development, and regional security. Participants highlighted key challenges including the shortage of skilled labor in the hydrogen sector, safety concerns and public fear due to limited information about hydrogen technologies, and the need for comprehensive capacity building and public awareness programs. The workshop also recognized positive social outcomes such as enhanced well-being through improved air quality, increased energy security fostering peace and interdependency among APEC economies, and the potential for rising happiness indices as GDP growth translates to household income improvements, though participants noted concerns about green hydrogen costs potentially impacting consumer product prices.

4.3.2 Technological Impact Assessment

The technological impact analysis encompasses both quantifiable infrastructure and demand metrics alongside qualitative innovation factors that drive hydrogen economy development. Model results demonstrate substantial shifts in hydrogen demand patterns, supply composition transitions from grey to green production methods, and significant investment requirements across scenarios. Complementing these measurable indicators, workshop insights reveal critical technological enablers including innovation acceleration, knowledge transfer effectiveness, and system integration challenges that determine the pace and success of hydrogen adoption across APEC economies, as summarized in the following table:

Table 4: Summary of technological impact assessment

Technology Category	Baseline (2023)	REF (2050)	CN (2050)	HEP (2050)
Global Hydrogen Demand	1,423 PJ	+166 PJ (13% growth)	+241 PJ (20% growth)	+595 PJ (48% growth)
Green Hydrogen Share	Minimal (3-4%)	Low (10-11%)	Moderate (11-12%)	Dominant (75-85%)
APEC Investment (2023-2050)		USD283 billion (~USD10 billion/year)	USD290 billion	USD326 billion (~USD12billion/year)
Innovation Speed	Current pace	Incremental improvements	Moderate acceleration	Rapid breakthroughs
Technology Transfer	Limited sharing	Basic collaboration	Enhanced cooperation	Comprehensive integration
System Integration	Isolated projects	Sector-specific development	Cross-sector coordination	Full infrastructure integration
Standards Development	Fragmented approaches	Basic harmonization	Regional alignment	Unified APEC standards

Quantitative Model Results The technological assessment reveals significant evolution in hydrogen demand, supply composition, and investment patterns across scenarios. Global hydrogen demand is projected to grow from 1,423 PJ in 2023 to increases of 13% under REF, 20% under CN, and 48% under HEP by 2050, with the transport sector showing the most dramatic expansion. Supply composition undergoes fundamental transformation, particularly under HEP where green hydrogen production dominates (797-729 PJ in APEC groups) compared to minimal levels in other scenarios. Cumulative investment requirements across APEC economies range from USD283 billion under REF to USD326 billion under HEP (2023-2050), representing approximately USD10-12 billion annually, with HEP showing increased investment in green hydrogen infrastructure while reducing dependence on grey hydrogen production.

Workshop Foresight Insights The foresight workshop identified critical technological dimensions beyond quantifiable metrics, emphasizing the interconnected nature of innovation, knowledge transfer, and system integration challenges. Participants highlighted key factors including the speed of technological breakthroughs in hydrogen production and utilization, the effectiveness of technology transfer mechanisms within APEC economies, and the complexity of integrating hydrogen into existing energy infrastructure. The workshop recognized that accelerated technological advancement through collaborative research and knowledge sharing could result in faster innovation cycles and more efficient production methods, while also noting the importance of developing comprehensive technical standards and safety protocols to support widespread hydrogen adoption across diverse APEC economies.

4.3.3 Economic Impact Assessment

The economic impact analysis demonstrates the substantial growth potential of hydrogen economy development across APEC economies, with measurable GDP increases and hydrogen market value expansion varying significantly across scenarios. Current global GDP of USD111.8 trillion is projected to reach USD211.1 trillion by 2050 under baseline conditions, with hydrogen policy scenarios generating additional economic benefits of USD155-327 billion above baseline projections. The hydrogen economy value itself shows potential for dramatic expansion from USD28.7 billion globally in 2023 to USD40.1 billion under aggressive policy scenarios, representing up to 30% increases over baseline trajectories in leading APEC economies.

Table 5: Summary of economic impact assessment

Economic Category	Baseline (2023)	REF (2050)	CN (2050)	HEP (2050)
Global GDP	USD111.8 trillion	USD211.1 trillion (89% growth)	+USD155 billion above REF	+USD327 billion above REF
Hydrogen Economy Value	USD28.7 billion globally	USD32.6 billion	USD32.6 billion (5% above REF)	USD40.1 billion (30% above REF)
Investment Requirements	-	USD283 billion (APEC)	USD290 billion (APEC)	USD326 billion (APEC)
Energy Diversification	High fossil fuel dependence	Moderate diversification	Enhanced diversification	Significant fossil fuel reduction
New Business Models	Limited services	Basic Hydrogen applications	Moderate Hydrogen business growth	Extensive new Hydrogen economy
Material Supply Challenges	Current supply chains	Emerging bottlenecks	Moderate supply pressures	Significant rare earth demands
Electricity Price Impact	Baseline pricing	Minimal increases	Moderate price adjustments	Notable price increases

Economic Category	Baseline (2023)	REF (2050)	CN (2050)	HEP (2050)
R&D Investment Needs	Current levels	Limited additional R&D	Enhanced R&D requirements	Substantial R&D investment

Quantitative Model Results Economic modeling reveals substantial GDP growth potential across all scenarios, with baseline projections showing 84-147% growth by 2050 depending on the economy group, and hydrogen policy interventions adding USD155 billion under CN and USD327 billion under HEP scenarios relative to baseline. The hydrogen economy value demonstrates even more dramatic potential, growing from USD28.7 billion globally in 2023 to ranges of USD32.6 billion under conservative scenarios to USD40.1 billion under HEP, with Group 1 and Group 2 economies showing 29-30% increases over baseline projections. Investment requirements and returns vary significantly, with the HEP scenario requiring approximately USD326 billion in cumulative hydrogen investments across APEC economies while generating the highest economic returns through enhanced productivity and new market creation.

Workshop Foresight Insights The foresight workshop identified critical economic dimensions extending beyond GDP metrics, emphasizing the transformative potential of hydrogen economy development on traditional market structures and business models. Participants highlighted key opportunities including reduced dependency on fossil fuels through energy diversification, emergence of new hydrogen-related businesses and services that could significantly enhance GDP growth, and substantial investment requirements in R&D and green technologies infrastructure. However, the workshop also recognized significant challenges including potential electricity price increases, material scarcity issues for hydrogen equipment production, shortage of rare earth materials for hydrogen storage systems, and concerns about market domination and trade tensions, emphasizing the need for collaborative approaches to ensure equitable distribution of economic benefits across APEC economies.

4.3.4 Environmental Impact Assessment

The environmental impact analysis reveals the transformative potential of hydrogen economy development for achieving substantial emissions reductions across APEC economies. With historical CO_2 emissions growth of 1.9% annually leading to 21.4 billion tons of APEC emissions in 2023, the hydrogen policy scenarios demonstrate significant departure from baseline trajectories, achieving 30-40% total emissions reductions by 2050. Beyond quantifiable emissions metrics, the assessment encompasses broader environmental considerations including ecosystem health benefits, biodiversity impacts from infrastructure development, and lifecycle environmental effects of hydrogen production technologies that collectively determine the sustainability of different hydrogen development pathways.

Table 6: Summary of environmental impact assessment

Environmental Category	Baseline (2023)	REF (2050)	CN (2050)	HEP (2050)
Total APEC CO_2 Emissions	21.4 billion tons	20.9 billion tons (-0.1% annually)	14.7 billion tons (-30% total)	12.5 billion tons (-40% total)
Group 1 Emissions	8.0 billion tons	8.4 billion tons	5.4 billion tons (-36% from REF)	4.3 billion tons (-49% from REF)
Group 2 Emissions	13.1 billion tons	12.0 billion tons	9.0 billion tons (-26% from REF)	7.9 billion tons (-35% from REF)
Group 3 Emissions	0.26 billion tons	0.41 billion tons	0.35 billion tons (-14% from REF)	0.32 billion tons (-22% from REF)
Annual Emissions Trend	+1.9% historically	-0.1% decline	-1.4% decline	-2.0% decline
Carbon Capture Capacity	12 million tons	47 million tons	Significantly higher	Significantly higher
Ecosystem Health Benefits	Current conditions	Minimal improvement	Moderate improvement	Substantial improvement
Biodiversity Impact	Baseline pressures	Limited change	Moderate infrastructure impact	Significant infrastructure development
Water Resource Demands	Current usage	Stable requirements	Increased HYDROGEN production needs	High electrolysis water demands
Rare Earth Material Pressure	Current extraction levels	Limited additional demand	Moderate material requirements	Substantial material demands
Lifecycle Environmental Impact	Fossil fuel dominated	Gradual improvement	Moderate HYDROGEN	Comprehensive clean

Environmental Category	Baseline (2023)	REF (2050)	CN (2050)	HEP (2050)
			technology benefits	technology integration
Air Quality Improvement	Current levels	Minimal gains	Notable pollution reduction	Transformative air quality benefits

Quantitative Model Results Environmental modeling demonstrates dramatic emissions reduction potential across hydrogen policy scenarios, with baseline projections showing modest decline (-0.1% annually) to 20.9 billion tons by 2050, while policy interventions achieve substantial improvements. The CN scenario delivers 30% total APEC emissions reduction through -1.4% annual decline rates, with Group 1 achieving 36% reduction and Group 2 achieving 26% reduction from baseline levels. The HEP scenario demonstrates even greater environmental benefits with 40% total emissions reduction through -2.0% annual decline, reaching 49% reduction in Group 1 and 35% reduction in Group 2, while carbon capture capabilities expand significantly from 12 million tons in 2023 to 47 million tons under baseline and substantially higher levels under policy scenarios.

Workshop Foresight Insights The foresight workshop identified critical environmental dimensions extending beyond emissions metrics, emphasizing the interconnected nature of hydrogen development with broader ecological systems and resource sustainability. Participants highlighted key environmental benefits including long-term ecosystem health improvements from reduced air and water pollution, enhanced biodiversity protection through cleaner energy systems, and substantial contributions to climate change mitigation goals. However, the workshop also recognized potential environmental challenges including biodiversity impacts from large-scale hydrogen infrastructure development, natural resource depletion concerns particularly for water resources required in electrolysis and rare earth materials needed for equipment manufacturing, and the importance of comprehensive lifecycle environmental assessments to ensure that hydrogen production technologies deliver net environmental benefits while minimizing unintended ecological consequences.

4.3.5 Political/Trade Impact Assessment

The policy impact analysis examines the complex interplay between hydrogen economy development and international trade relationships, regulatory frameworks, and geopolitical dynamics across APEC economies. Current trade patterns show substantial net exports from APEC economies (USD6.6 trillion in 2023) with projections reaching USD13.0 trillion by 2050 under baseline conditions, while hydrogen policy scenarios demonstrate both challenges and opportunities in trade relationships. Beyond quantifiable trade metrics, the assessment reveals critical policy dimensions including the need for harmonized regulatory frameworks, enhanced APEC collaboration mechanisms, and strategic approaches to managing geopolitical shifts as energy dependencies transform through hydrogen adoption.

Table 7: Summary of policy impact assessment

Policy Category	Baseline (2023)	REF (2050)	CN (2050)	HEP (2050)
Total APEC Trade Volume	USD61.8 trillion	USD115.8 trillion	-USD425 B vs REF	-USD590 B vs REF
Net Export Position	-	-	+USD20 B improvement	+USD35 B improvement
Group Trade Impact	Strong surplus position	Continued growth	Maintained advantage	5% reduction in surplus
Group 2&3 Trade Outcomes	Mixed positions	Positive trajectory	Enhanced outcomes	Strong positive results
Hydrogen Trade Value	Baseline levels	-2% decline	+3% growth	+26% increase
Energy Dependency	High oil dependency	Continued fossil reliance	Moderate diversification	Significant oil reduction
APEC STI Collaboration	Limited coordination	Basic cooperation	Enhanced partnerships	Strong integration
Regulatory Framework	Fragmented standards	Minimal harmonization	Moderate alignment	Comprehensive APEC standards
International Agreements	Bilateral focus	Limited multilateral	Enhanced cooperation	Strong collaborative frameworks
Geopolitical Stability	Current tensions	Existing challenges	Improved through cooperation	Enhanced regional stability
Policy Alignment	Diverse approaches	Continued fragmentation	Increased coordination	Unified policy direction
Trade Barriers	Existing restrictions	Maintained barriers	Reduced impediments	Harmonized trade facilitation
Carbon Trade Mechanisms	Early development	Limited progress	Moderate advancement	Comprehensive APEC system

Quantitative Model Results Policy modeling demonstrates significant shifts in trade patterns and international economic relationships across hydrogen development scenarios. Total trade volumes are projected to reach USD115.8 billion by 2050 under baseline conditions, with policy scenarios showing reduced total trade (-USD425-590 billion) but improved net export positions (+USD20-35 billion) relative to baseline. APEC Groups 2 and 3 show positive trade outcomes across scenarios, while Group 1 may experience up to 5% reduction in trade surplus under aggressive hydrogen policies. Hydrogen trade specifically demonstrates dramatic variation, declining 2% under REF but growing 3% under CN and increasing 26% under HEP, indicating the potential for hydrogen to become a significant new trade commodity that reshapes traditional energy trade relationships across the region.

Workshop Foresight Insights The foresight workshop identified critical policy dimensions extending beyond trade metrics, emphasizing the transformative potential of hydrogen economy development for regional collaboration and regulatory harmonization. Participants highlighted key opportunities including strengthened APEC STI collaborations, accelerated achievement of carbon neutrality goals through coordinated policies, and enhanced energy security through reduced oil dependency and shared hydrogen infrastructure development. However, the workshop also recognized significant policy challenges including the need for unified regulatory frameworks covering hydrogen verification and carbon trading, concerns about trade barriers and CBAM implications for developing economies, geopolitical tensions over hydrogen technology and resources, and the imperative for clear hydrogen policies along entire supply chains. The assessment emphasized that successful hydrogen economy development requires unprecedented levels of political collaboration, standardized regulations across APEC economies, and careful management of the geopolitical implications as hydrogen emerges as a new dimension of energy diplomacy and trade relationships.

4.4 Comparative Scenario Analysis

The comprehensive assessment across social, technological, economic, environmental, and policy dimensions reveals that collaborative hydrogen economy development through the HEP scenario delivers substantially superior outcomes compared to individual economy efforts or moderate policy approaches. The analysis demonstrates that when APEC economies work together on hydrogen trade, technology sharing, and coordinated policy implementation, the resulting synergies unlock exponentially greater benefits across all impact categories.

The HEP scenario significantly outperforms baseline and moderate policy approaches across all key metrics. Economically, collaborative hydrogen development generates USD327 billion in additional GDP above baseline by 2050, more than double the USD155 billion achieved under the Carbon Neutrality scenario. Environmental benefits are equally compelling, with HEP achieving 40% emissions reduction to 12.5 billion tons compared to 30% reduction under CN, representing an additional 2.2 billion tons of CO_2 avoided annually. Employment creation shows the most dramatic differential, with HEP generating 30 million additional jobs versus 9.3 million under CN, indicating that collaborative approaches create employment multiplier effects across upstream and downstream sectors.

The technological transformation under HEP demonstrates the power of coordinated investment and knowledge sharing. Hydrogen demand growth reaches 48% under collaborative scenarios compared to 20% under moderate policies, while green hydrogen production expands to 1,724 PJ representing 85% of total supply, a dramatic shift from the 184 PJ (11%) achieved under individual economy efforts. This transformation requires redirecting USD126.1 billion toward green hydrogen infrastructure under HEP versus only USD22.0 billion under CN, demonstrating that ambitious collaboration demands correspondingly ambitious investment commitment. The hydrogen economy value itself becomes 30% larger in Group 1 economies and 29% larger in Group 2 under collaborative approaches, creating substantial new markets and business opportunities that individual efforts cannot achieve. This analysis conclusively demonstrates that collaboration provides the optimal pathway for hydrogen implementation across the APEC region, unlocking greater economic opportunities, accelerated innovation, and transformative sustainable growth that benefits all participating economies.

Table 8: Summary of impact assessment

Impact Category	REF	CN	HEP	HEP vs CN Advantage
Economic Growth (Additional GDP by 2050)	Baseline	+USD155 billion	+USD327 billion	+USD172 billion more
Environmental Impact (CO2 Reduction)	Minimal (-0.1% annually)	30% reduction (14.7B tons)	40% reduction (12.5B tons)	Additional 2.2B tons avoided
Job Creation	5.2 million jobs	9.3 million additional jobs	30 million additional jobs	+20.7 million more jobs
Hydrogen Demand Growth	13% growth	20% growth (1,664 PJ)	48% growth (2,018 PJ)	+28% higher growth
Green Hydrogen Production	73-80 PJ (10-11%)	184 PJ (11% of supply)	1,724 PJ (85% of supply)	+1,540 PJ more (+74% share)
Green Hydrogen Investment	USD21.3 billion	USD22.0 billion	USD126.1 billion	+USD104.1 billion more
Hydrogen Trade Growth	-2% decline	+3% growth	+26% growth	+23% higher growth
APEC Collaboration Level	Limited	Moderate partnerships	High integration	Comprehensive cooperation

Impact Category	REF	CN	HEP	HEP vs CN Advantage
Technology Transfer	Minimal sharing	Selective cooperation	Comprehensive integration	Full knowledge sharing
Policy Coordination	Fragmented	Partially coordinated	Highly coordinated	Unified regional approach

Key Finding: The HEP scenario demonstrates that **collaborative hydrogen economy development delivers 2-10 superior outcomes** across all metrics compared to individual economy efforts, proving that regional cooperation is essential for maximizing hydrogen economy benefits.

5. FINDINGS AND RECOMMENDATIONS

Key Findings

1. **Low-carbon hydrogen viability:** Low-carbon hydrogen will become a practical and implementable solution driven by global climate commitments and technological advancements. Global hydrogen demand reached 97 million tons in 2023, with low-emissions hydrogen production potentially reaching significant levels by 2030 based on announced projects. China leads in committed projects and could account for almost 70% of electrolyser capacity, while progress is particularly strong in Japan and Korea for power sector applications (IEA Global Hydrogen Review, 2024).
2. **Trade importance:** APEC trade in hydrogen is vital for advancing hydrogen adoption across member economies, enabling economies with varying resources and capabilities to participate in the hydrogen transition. Regional hydrogen trade is expected to grow significantly by 2040, with Australia; Canada; and Chile potentially emerging as key exporters.
3. **Standardization necessity:** Standardization is crucial to harmonize efforts and support the development of a functional hydrogen market across the APEC region. Common standards reduce barriers to trade and technology adoption, supporting the implementation of harmonized approaches that can facilitate regional economic integration.
4. **STI solutions:** Science, Technology, and Innovation solutions are essential for accelerating green hydrogen policies within APEC, providing the technological foundation for policy implementation. APEC economies demonstrate variable readiness levels across the region, reflecting different stages of economic development and technological capabilities in hydrogen infrastructure deployment.
5. **Technology transfer:** Technology and knowledge transfer are crucial for ensuring widespread hydrogen innovation and use, particularly for developing economies within APEC. Enhanced technology cooperation and capacity building initiatives can significantly accelerate hydrogen adoption across economies with varying levels of development, supporting the region's transition to clean energy systems.

Social Acceptance as a Critical Factor

This project identified "social acceptance" as a key factor in hydrogen transition. Research studies indicate that public awareness and acceptance of hydrogen technologies vary significantly across regions, with many people having limited knowledge about hydrogen applications and safety. Addressing public concerns about safety, awareness, and job impacts through education, safety standards, and transparent communication is essential for securing public and stakeholder support in the hydrogen economy.

Without adequate social acceptance, even the most technically sound hydrogen implementation plans may face barriers to adoption. This project recommends dedicated efforts to:

- Develop public education and awareness programs
- Establish transparent safety protocols and communication channels

- Create inclusive stakeholder engagement processes
- Address workforce transition concerns through training and development programs

Policy Recommendations

Based on the comprehensive analysis, this project recommends:

1. Standardized Hydrogen Policies:
    - Create a borderless hydrogen market across APEC economies
    - Develop harmonized regulatory frameworks and certification systems
    - Establish common safety standards and protocols (aligned with the International Hydrogen Safety Association guidelines)
    - Boost cross-border trade through reduced regulatory barriers
2. Technology Transfer Mechanisms:
    - Encourage hydrogen technology transfer through dedicated programs
    - Create collaborative research initiatives across APEC economies
    - Establish technology demonstration projects with multi-economy participation
    - Develop shared intellectual property frameworks to facilitate knowledge exchange
3. Workforce Development:
    - Create targeted training programs for green jobs in the hydrogen sector
    - Develop certification standards for hydrogen technicians and specialists
    - Establish worker exchange programs between APEC economies
    - Create transition pathways for workers from traditional energy sectors, particularly important as APEC economies account for a significant portion of global fossil fuel employment, with the region representing 56% of world energy demand and 58% of world energy supply (Lima Statement 2024 APEC Energy Ministerial Meeting
4. Infrastructure Investment:
    - Develop coordinated investment plans for hydrogen infrastructure
    - Create shared standards for hydrogen storage, transport, and utilization
    - Establish cross-border infrastructure projects to facilitate hydrogen trade
    - Develop financing mechanisms to support infrastructure development, building on APEC's established frameworks including the APEC Finance Ministers' Process initiatives on quality infrastructure development and sustainable finance
5. Research Collaboration:
    - Facilitate connections between hydrogen experts among APEC economies

- Coordinate research priorities to avoid duplication of efforts
- Share research facilities and capabilities across economies
- Establish regular knowledge-sharing forums and workshops to create expanded opportunities for hydrogen technology collaboration and potentially develop dedicated hydrogen innovation tracks.