# Strengthening Climate Resilience and Food Security via Stakeholder-Driven Sustainable Seaweed Supply Chains

APEC Ocean and Fisheries Working Group

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# TABLE OF CONTENTS

# 1. Background

Recent global climate crises and geopolitical tensions have exposed significant vulnerabilities in food production systems worldwide. At the same time, the global population will reach 10 billion by 2050 (World Bank, 2019), underscoring the growing importance of seaweed as an alternative food and bioresource that can support rising food demand. The Asia–Pacific region, which accounts for approximately 40% of the world's population and half of global trade (ESCAP, 2023), remains directly exposed to environmental changes in coastal areas and the associated risks of declining marine resources. Under these conditions, seaweed aquaculture has rapidly emerged as one of the most promising and environmentally friendly solutions for advancing the Blue Economy and achieving the Sustainable Development Goals (SDGs) (World Bank, 2023).

Global production and market trends further highlight this potential. As of 2022, seaweed aquaculture production reached about 36.5 million tonnes (wet weight) and was valued at USD 17 billion, making up roughly 27% of global aquaculture output (FAO, 2024). Production remains highly concentrated, led by China, followed by Indonesia; Korea; the Philippines, and several other economies that together represent a smaller portion of global output (FAO, 2024; Seaweed Insights, 2023). These production trends, along with market forecasts suggesting the global seaweed industry will grow from USD 9.01 billion in 2024 to USD 18.36 billion by 2033 (CAGR 8.17%), strengthen the sector's strong long-term growth outlook (IMARC Group, 2025; Ferdouse et al., 2018).

Seaweed aquaculture is increasingly seen as an industry that combines economic, environmental, social, and health goals. It offers significant benefits such as creating jobs in coastal communities, establishing sustainable food supply chains, helping fight climate change through blue carbon pathways, increasing participation of women and older workers, supporting marine ecosystem restoration, and fostering rural and coastal development (United Nations Environment Programme, 2023; ASC–MSC, 2023). For these reasons, seaweed aquaculture is viewed as a multi-sectoral industry with strong potential to promote inclusive and sustainable development at both domestic and regional levels.

## 1.1. Objectives and Methodology

This report aims to provide a comprehensive analysis of how seaweed can support climate change mitigation and adaptation, food and nutrition security, and the development of high-value industries across the APEC region. It examines the current status of production, trade, and supply chain challenges; identifies opportunities for industrial upgrading; and proposes strategic policy directions to build a sustainable and resilient seaweed sector. Additionally, the report highlights three key best-practice cases—Indonesia's blue-carbon governance framework; Japan's J-Blue Credit® scheme; and Korea's laver (Gim) industry—to derive policy lessons applicable throughout APEC economies. The study uses a mixed-methods approach:

- **Literature Review**
  Key sources—including FAO statistics, APEC publications, World Bank reports, academic journals, and policy documents—were reviewed to analyze global and regional trends in seaweed production, trade, technology, and climate policy.

- **Key Informant Interviews**
  Semi-structured interviews were conducted with government officials, researchers, private-sector representatives, and producer groups from major seaweed-producing economies such as China; Indonesia; Korea; and the Philippines, providing context-specific insights and validating survey findings.

- **Survey Research**
  An online survey was conducted via SurveyMonkey from 1-30 October 2025, targeting stakeholders from APEC economies and beyond to identify supply-chain challenges, development needs, and climate-resilience priorities in the seaweed sector.

- **Expert Consultation**
  Subject-matter experts in aquaculture, climate policy, blue carbon, and food-system resilience were consulted to improve analytical frameworks and ensure the relevance and feasibility of policy recommendations.

### 1.2. Discussion on Seaweed Utilization

APEC — the Asia-Pacific Economic Cooperation — links economies with extensive coastlines across the broader Asia–Pacific region, many of which are highly vulnerable and sensitive to climate change impacts. Meanwhile, Asian economies account for about 98% of the world's seaweed production (FAO, 2025a). Seaweed use has become a promising area for industrial growth, providing opportunities for economic diversification, climate mitigation, and energy security. This potential is already evident through ongoing policy cooperation within APEC. The APEC Energy Working Group (EWG) actively promotes collaboration on sustainable seaweed-based bioenergy (APEC Energy Working Group, 2025), while the APEC Ocean and Fisheries Working Group (OFWG) explores frameworks that support sustainable aquaculture — including seaweed farming — to enhance climate resilience and boost economic benefits for coastal communities in the region.

## 2. Status of Seaweed in the APEC Region

### 2.1. Types of seaweed

Seaweeds can be broadly categorized into microalgae, which are free-floating organisms including plant-like plankton, and macroalgae, which are attached multicellular forms conventionally referred to as seaweeds. Although species such as kelp or laver may appear to possess stems or leaves, they are, in biological terms, multicellular thalli that lack differentiated vascular organs. Seaweeds are generally classified according to their dominant pigment groups and the depth and light conditions of their habitats, forming three major groups: green algae (Chlorophyta), brown algae (Phaeophyceae), and red algae (Rhodophyta) (Britannica, 2025; Gijang-gun, 2025).

**Brown algae**—including kelp, wakame, Sargassum, and Hizikia—are predominantly marine and widely used in East Asian cuisine.

- **Wakame** is commonly used in soups and is rich in calcium and iodine.

- **Kombu/kelp** serves as a key base for broths and contains high levels of alginic acid, which supports digestive health.

- **Hijiki** is valued for its high dietary fiber and iron content, particularly in Japanese and Korean dishes.

- **Sargassum**, a floating species, plays an important ecological role as habitat and nursery ground in marine ecosystems.
  Major producers of brown algae include Chile; China; Indonesia; Japan; Korea; the Philippines; and the United States.

**Red algae**—such as agarophytes, carrageenophytes, and nori—are also primarily marine and are essential sources of hydrocolloids.

- **Nori/laver** is consumed roasted or dried and is rich in protein and B vitamins.

- **Agar-agar** derived from Gelidium and Gracilaria serves as the raw material for agar used in jellies and puddings.

- **Kappaphycus**, the principal source of carrageenan, is widely used as a thickener and stabilizer in ice cream, yogurt, and other processed foods.

- **Gracilaria** contains high agar content and is used in food, cosmetics, and other industrial applications.
  Red algae are primarily produced in China, Japan, Korea, and the Philippines.

**Green algae**, while found in both marine and freshwater environments, represent only a subset of oceanic species. Key producing economies for green algae include China; Japan; Korea; and the Philippines.

- **Ulva (sea lettuce)** is known for its soft texture and is used in soups and salads.

- **Chondrus crispus** (Irish moss) has a fine, filamentous structure and is used in salads and side dishes.

- **Spirulina**, a protein- and antioxidant-rich microalga, is widely consumed as a health supplement.

- **Chlorella** is recognized as a nutrient-dense “superfood,” associated with immune enhancement and detoxifying effects.

Across all three groups, seaweeds are rich in essential minerals—including iodine, calcium, potassium, iron, magnesium, and selenium—along with functional polysaccharides such as alginate, fucoidan, laminarin, agar, and carrageenan. Combined with vitamins A, C, and E, these bioactive components support seaweeds’ growing recognition as a key part of functional nutrition, with uses in food, health products, and bio-industrial applications.

## 2.2. Status of Production and Trade of Seaweed

### 2.2.1. Status of the Global Seaweed Production

Global seaweed production reached approximately 38 million tonnes in 2022, indicating that seaweeds make up nearly all of the algae aquaculture sector (FAO, 2025c; Zhou et al., 2025). Production is heavily concentrated in Asia: China; Indonesia; Korea; and the Philippines together account for 96.1 percent of global farmed algae output. In contrast, capture-based seaweed harvesting remains minimal, limited to a few cold-temperate kelp fisheries, representing only a small share

compared to aquaculture.

Regarding species composition, global aquaculture production is primarily dominated by a small group of seaweed species. FAO (2023) shows that Saccharina japonica alone makes up about 35.2 percent of global farmed algae production, followed by Eucheuma/Kappaphycus (21.9 percent) and Gracilaria (18.7 percent). Undaria pinnatifida and Porphyra/Pyropia species account for 7.1 percent and 5.6 percent, respectively, while all other species (including Ulva, Sargassum, and Monostroma) each make up less than 2 percent individually. This indicates that five major species groups account for nearly 90 percent of the global farmed seaweed supply.

**Table 1. Major seaweed groups in global aquaculture (2023)**

| Species group | Share of global aquaculture algae production (2023) |
|---|---|
| **Saccharina japonica** | 35.2% |
| **Eucheuma spp (incl. Kappaphycus)** | 21.9% |
| **Gracilaria spp** | 18.7% |
| **Undaria pinnatifida** | 7.1% |
| **Porphyra / Pyropia spp** | 5.6% |
| **Other species (Ulva / Sargassum / Monostroma etc.)** | each < 2% individually |

Source: **FAO (2025)**

### 2.2.2. Status of the Global Seaweed Trade

Global seaweed trade, however, remains comparatively small relative to its production volume (FAO, 2025c). In 2023, exports of seaweeds and other algae fit for human consumption (HS1212.21) reached USD 801 million, while exports of seaweeds and other algae unfit for human consumption (HS1212.29) amounted to USD 371 million. Taken together, these two HS codes total approximately USD 1.17 billion in 2023, which corresponds to well below 1 percent of global aquatic product exports in value terms. FAO's HS-based reporting also indicates that agar-agar (HS1302.31), a derivative commodity originating largely from seaweed inputs, accounted for an additional USD 278 million in exports in 2023, further illustrating that a notable share of trade value is captured in downstream processed/extracted products rather than in raw biomass alone.

**Table 2. Seaweed Export values in 2023**

| HS code | Description | Export Value (USD million) | Global share |
|---|---|---|---|
| **1212.21** | Seaweeds and other algae, fit for human consumption | 801 | 0.4% |
| **1212.29** | Seaweeds and other algae, unfit for human consumption | 371 | 0.2% |
| **1302.31** | Agar-agar | 278 | 0.2% |

Source: **FAO (2025c)**

## 2.3. Status of Production and Trade of Seaweed in the APEC Region

### 2.3.1. Status of Production

The APEC region is the world's leading area for seaweed production, making up over 95% of the global seaweed output in aquaculture (FAO, 2025a). Production mainly occurs in a few key economies, including Chile; China; Indonesia; Japan; Korea; and the Philippines, which together define the overall supply structure. Despite notable differences in scale, species, and farming techniques, the region has a complementary production profile that supports global markets for food, hydrocolloids, functional ingredients, and emerging bio-based industries.

China is by far the largest producer, accounting for over 23 million tonnes in 2023, or more than half of global production (FAO, 2025a). Its industry is characterized by large-scale marine aquaculture of Laminaria japonica, Gracilaria spp., Porphyra spp., and Undaria, supported by mechanized longline systems and extensive processing infrastructure.

Indonesia ranks as the second-largest producer, with 9.8 million tonnes, primarily driven by aquaculture. The economy mainly focuses on carrageenan-producing red seaweeds—Kappaphycus and Eucheuma—as well as Gracilaria (FAO, 2025a; Seaweed Insights, 2023). Indonesia is the top global supplier of raw materials for the carrageenan industry, though most of its production is exported in dried form due to limited domestic processing capacity.

The Republic of Korea maintains a highly efficient, export-oriented industry producing approximately 1.8 million tons annually (FAO, 2025a). Production is dominated by Pyropia (laver), Undaria (wakame), and Saccharina (kelp), supported by advanced seeding techniques, standardized quality control, and digital farming systems. Korea remains a global leader in value-added seaweed products, especially dried laver.

The Philippines produced about 1.6 million tonnes in 2023, almost entirely from aquaculture (FAO, 2025a). Its production mainly consists of Kappaphycus and Eucheuma, making it a significant contributor to the global carrageenan supply chain. The industry is composed of small-scale farmers, whose production is vulnerable to climate variability, disease, and price fluctuations.

Japan’s production, at roughly 0.3 million tonnes, is small compared to regional leaders but highly specialized (FAO, 2025a). Its output focuses on premium-quality

Porphyra (nori), Saccharina (kombu), and Undaria (wakame). Japan remains a global benchmark for high-value processing, branding, and culinary-grade seaweed.

Chile is the region's leading producer of wild-harvested seaweeds, with over 450,000 tonnes collected in 2023 (FAO, 2025a; Chile, 2025). Capture production makes up most of the output, especially Chilean kelp (Lessonia and Macrocystis species) and Gracilaria. Chile's unique production system serves both the alginate and agar industries.

Thailand, although not a major producer, contributes a small volume of aquaculture (around 1,000 tonnes in 2023) and serves as an important processing and re-export hub, relying heavily on imports from other APEC economies (The nation, 2025).

**Table 3. Seaweed Production and Major Species in APEC Economies (2023)**

| Economy | Total Production (tons) | Aquaculture | Capture | Major Species Produced |
|---|---|---|---|---|
| **Chile** | 451,576 | 15,476 | 467,052 | Chilean kelp (*Lessonia/Macrocystis* complex), *Gracilaria* spp., Bull kelp (*Durvillaea*) |
| **China** | 23,060,000 | 23,060,000 | - | Laminaria japonica *(kelp),* Gracilaria *spp.,* Porphyra *spp. (nori),* Undaria pinnatifida *(wakame),* Sargassum *spp.* |
| **Indonesia** | 9,837,730 | 9,753,410 | 84,320 | Eucheuma/Kappaphycus *(carrageenophytes),* Gracilaria *spp.,* Caulerpa *spp., small share of* Sargassum |
| **Japan** | 299,000 | 299,000 | - | Porphyra *(nori),* Saccharina *(kombu),* Undaria *(wakame)* |
| **Republic of Korea** | 1,74,000 | 1,74,000 | - | Pyropia *(laver),* Undaria *(wakame),* Saccharina *(kelp)* |
| **The Philippines** | 1,627,090 | 1,617,178 | 9,912 | Kappaphycus/Eucheuma *(elkhorn sea moss),* Spiny Eucheuma, Caulerpa*, minor* Gracilaria |
| **Thailand** | 1,031 | 1,031 | - | Caulerpa, Ulva *(very small scale), Nori NEI (mainly processing-based supply chain)* |

Source: **FAO, 2025a, c, Chile(2025)**

### 2.3.2. Status of Trade

APEC economies play a key role in the global seaweed trade, making up most of the world's exports and imports and shaping the global value chain from raw material extraction to advanced processing. Trade patterns in the region include large production hubs in East and Southeast Asia, strong processing and hydrocolloid industries, and quickly growing consumer markets (World Bank, 2023).

On the export side, APEC economies lead the global supply. China remains the world's top exporter of processed seaweed products, especially agar, carrageenan, dried kelp, and other hydrocolloids, using its extensive processing capacity and integrated aquaculture–manufacturing system. Korea excels in value-added consumer seaweed products, driven mostly by the success of K-laver. Laver exports have almost tripled in the past decade, establishing Korea as a global leader in roasted and seasoned seaweed snacks. Indonesia and the Philippines supply most of the world's Eucheuma and Gracilaria raw materials, forming the foundation of the global carrageenan industry (Seaweed Insights, 2023). Japan's exports are smaller but focus on high-quality nori and value-added snack products. Together, these economies account for over 80% of the global seaweed export value, reflecting the region's dominant role in both raw and processed markets.

On the import side, APEC economies show strong complementarities within the regional supply chain. China imports large quantities of Eucheuma and Gracilaria from Chile; Indonesia; and the Philippines to support its growing hydrocolloid manufacturing sector. This setup highlights China's reliance on external raw materials despite its dominance in processing. Japan imports significantly more seaweed than it exports, mainly sourcing from Korea and China to support its food-processing industry and stay competitive on price.

Korea's imports are relatively limited and focus on industrial raw materials like dried kelp and carrageenan feedstock, while its edible seaweed market remains largely self-sufficient. Southeast Asian economies such as Thailand and Viet-nam are increasingly importing processed laver and seaweed snacks from China and Korea, reflecting changing dietary preferences and growth in the packaged-food sector. Meanwhile, Australia; Canada; the United States and other Pacific economies are experiencing rising demand for seaweed-based foods and functional ingredients, further strengthening APEC's role as both a major producer and a rapidly expanding consumer region.

## 2.4. Market Outlook for the Seaweed Industry

Recent international statistics show that global seaweed production has grown significantly over the past twenty years. Total output reached about 36.3 million tonnes in 2021, compared to roughly 11.8 million tonnes in 2001 (FAO, 2025b). Most production is farm-based: around 97 percent of the global supply comes from aquaculture, while wild-harvest volumes remain relatively small and stable. The supply is also geographically concentrated, with four Asia-Pacific economies—China; Indonesia; Korea; and the Philippines—making up the majority of worldwide production.

International trade in seaweed products has increased in both volume and value. In 2023, global exports reached around 819,100 tonnes, with an estimated export value of USD 3.21 billion. Product composition in trade flows is dominated by carrageenan-related categories, accounting for about 47.8 percent of traded seaweed, followed by products intended for direct human consumption at about 32.2 percent (FAO, 2025). Indonesia is currently the largest exporter by volume, while

China records the highest export value. China is also the largest import market globally, taking in about 43 percent of world import volumes, with Japan; the United States; Germany; and Spain among other major destination markets.

In downstream applications, seaweed is used across a wide range of industries. Its inclusion in processed foods is still common, and hydrocolloid derivatives — such as carrageenan, agar, and alginate — are extensively employed in food processing and pharmaceutical manufacturing as functional agents that provide gelling, stabilizing, or thickening properties. Research and commercial development efforts also continue in other areas, including biostimulants and livestock feed formulations. Interest in these applications is supported by bioactive properties found in specific seaweed species and by cultivation methods that do not require freshwater, fertilizers, or pesticides, while remaining compatible with marine environmental conditions.

# 3. Seaweed Supply Chains and Stakeholders in the APEC Region

## 3.1. Challenges across the Seaweed Supply Chain in the APEC Region

Based on the survey conducted from 1-30 October 2025, using SurveyMonkey, a total of 20 respondents from APEC and non-APEC economies—including government agencies, research institutions, private companies, producer groups, and international organizations—provided insights into the systemic challenges affecting the performance and resilience of seaweed supply chains in the region. The responses reflect perspectives from both large-scale commercial producers and smallholder or community-based farming systems, offering a comprehensive view of the constraints impacting production, processing, trade, and market development across different contexts.

- **Production Stage Challenges**

Survey responses consistently highlighted climate-driven instability as the biggest threat to seaweed production. Rising sea surface temperatures, storms, and ENSO-related anomalies (El Niño/La Niña) were found to directly impact growth rates and seasonal yields. Biological risks—including disease outbreaks, bacterial infections, and site contamination—were also repeatedly mentioned as factors that reduce production stability. A shortage of high-quality seedstock and poor seed quality control standards are ongoing challenges, especially in economies with uneven or underdeveloped seed supply chains. Many respondents also noted that production still depends on traditional, labor-intensive methods, which creates persistent productivity gaps and technological disparities among producers. Infrastructure limitations—such as aging farming equipment, space conflicts in coastal zones, and misalignment with environmental regulations—were also identified as major structural obstacles.

**Table 4. Key Bottlenecks Across the Seaweed Supply Chain**

| Supply Chain Stage | Priority Level | Key Challenges | Detailed Issues Identified |
|---|---|---|---|
| **Production** | High | Climate-driven instability | • Rising SST, storms, ENSO (El Niño/La Niña) anomalies causing variability in growth and seasonal yields |
| | High | Seedstock shortages & poor-quality control | • Limited access to high-quality seedlings<br>• Weak quality control standards<br>• Uneven seed supply chains |
| | Medium | Biological risks | • Disease outbreaks, bacterial infections, site contamination |
| | Medium | Labor-intensive traditional methods | • Reliance on manual, traditional practices → productivity gaps and technological disparities |
| | Low | Infrastructure limitations | • Aging farming equipment<br>• Coastal space-use conflicts<br>• Misalignment with environmental regulations |

- **Harvesting and Post-Harvest Handling Challenges**

Participants reported that inconsistent handling practices during harvesting and drying contribute to significant quality differences across products. Inadequate removal of salt, sand, and foreign materials was frequently linked to decreased product value and reduced export competitiveness. Many economies still rely heavily on natural sun-drying, which makes product quality highly vulnerable to rainfall, humidity fluctuations, and other climate conditions. The lack of standardized protocols for harvesting, drying, sanitation, and quality inspection was identified as a common concern. Respondents also pointed out delays between harvesting, sorting, and transportation, often leading to spoilage and quality decline due to inadequate post-harvest logistics systems.

**Table 5. Key Bottlenecks Across the Seaweed Supply Chain**

| Supply Chain Stage | Priority Level | Key Challenges | Detailed Issues Identified |
|---|---|---|---|
| **Harvesting & Post-Harvest Handling** | High | Quality variability due to inconsistent handling | • Incomplete removal of salt, sand, and foreign materials → reduced product value and export competitiveness |
| | High | Dependence on natural sun-drying | • Vulnerability to rainfall, humidity, and climate fluctuations |
| | Medium | Lack of standardized | • Absence of uniform guidelines for harvesting, drying, sanitation, |

| | | | |
|---|---|---|---|
| | | protocols | and quality inspection |
| | Low | Post-harvest logistics delays | • Slow sorting, transport, and storage processes → spoilage and quality decline |

- **Processing Stage Challenges**

Many developing APEC economies lack sufficient processing capacity, leading to a supply chain mainly exporting low-value raw dried seaweed instead of higher-value products. The hydrocolloid industry—including agar, carrageenan, alginate, and fucoidan—confronts challenges such as limited technology, low investment, and a shortage of specialized equipment. Outdated or inadequate processing facilities make it hard for producers to consistently meet international quality standards like HACCP, GMP, and similar certifications. Limited R&D capabilities and the absence of advanced processing technologies restrict access to premium markets such as functional foods, bioplastics, pharmaceuticals, and cosmetics. These issues collectively form a structural bottleneck, preventing many economies from advancing up the value chain.

**Table 6. Key Bottlenecks Across the Seaweed Supply Chain**

| Supply Chain Stage | Priority Level | Key Challenges | Detailed Issues Identified |
|---|---|---|---|
| **Processing** | High | Insufficient processing capacity | • Dependence on exporting low-value raw dried seaweed<br>• Inability to scale higher-value processing |
| | High | Outdated equipment & inability to meet international standards | • Difficulties meeting HACCP, GMP, and other global certifications |
| | Medium | Hydrocolloid industry limitations (agar/carrageenan/alginate/fucoidan) | • Limited technology, investment, and specialized equipment |
| | Low | Weak R&D & limited access to advanced processing technologies | • Restricted entry into premium markets such as functional foods, bioplastics, pharmaceuticals, and cosmetics |

## 3.2. Distribution and Trade Stage Challenges

Survey results show that trade-related barriers—such as limited access to international markets, complicated quality standards, and rules of origin—still act as significant bottlenecks. Variability in quality within smallholder-led supply chains also

hampers consistent compliance with buyer expectations for moisture content, viscosity, gel strength, and other specs. Respondents highlighted the lack of packaging, storage, and cold-chain infrastructure, which leads to quality deterioration and higher logistics costs. In several economies, a limited understanding of export certifications—including organic standards and sustainability labels—restricts opportunities to access high-value international markets.

**Table 7. Key Bottlenecks Across the Seaweed Supply Chain**

| Supply Chain Stage | Priority Level | Key Challenges | Detailed Issues Identified |
|---|---|---|---|
| **Distribution & Trade** | High | Trade barriers & complex quality standards | • Limited market access<br>• Stringent specifications (gel strength, viscosity, moisture content) |
| | Medium | Quality inconsistency in smallholder supply chains | • Variability in product specifications across producers |
| | Low | Packaging, storage, and cold-chain limitations | • Quality deterioration and increased logistics costs |
| | Low | Limited understanding of export certifications | • Insufficient knowledge of organic certifications and sustainability labels |

- **Governance and Institutional Challenges**

Many respondents emphasized inadequate government investment in R&D, weak extension services, and the lack of coherent domestic strategies for seaweed development. The dominance of smallholder producers, combined with weak producer organizations and cooperative structures, was linked to low bargaining power and high dependence on intermediaries. Regulatory complexity also emerged as a recurring issue. Participants described slow or fragmented licensing processes and limited coordination among government ministries as factors that hinder industry growth. Policy inconsistencies across quality standards, environmental rules, spatial planning, and aquaculture regulations were widely seen as reducing overall supply chain efficiency.

**Table 8. Key Bottlenecks Across the Seaweed Supply Chain**

| Supply Chain Stage | Priority Level | Key Challenges | Detailed Issues Identified |
|---|---|---|---|
| **Governance & Institutional Factors** | High | Insufficient government R&D investment & weak extension services | • Lack of technical support<br>• Fragmented or insufficient public investment |

| | | |
|---|---|---|
| Medium | Weak producer organizations | • Low bargaining power<br>• Heavy dependence on intermediaries |
| Medium | Regulatory complexity & licensing delays | • Slow or fragmented permitting processes<br>• Limited inter-ministerial coordination |
| Low | Policy inconsistencies | • Misalignment among quality standards, environmental rules, spatial planning, and aquaculture regulations |

## 3.3. Development Needs for Strengthening Seaweed Supply Chains in the APEC Region

- **Development Needs in the Production Stage**

Survey responses show a strong demand for technologies that improve climate resilience in seaweed farming systems. Stakeholders highlighted the need for innovations such as heat-tolerant strains, farm structures that can withstand typhoons and wave surges, and environmental monitoring systems that enable smart, adaptive farming practices. Securing high-quality seed stock was repeatedly identified as a key priority, with calls to strengthen domestic seed centers and create regionally distributed seed supply networks. Respondents also stressed the importance of expanding extension services and hands-on training programs to boost productivity among small-scale farmers. In several economies, establishing clear aquaculture zoning, improving water-quality management, and implementing real-time environmental monitoring systems were also seen as essential to stabilizing production.

- **Development Needs in Harvesting and Post-Harvest Handling**

Many respondents emphasized that reducing dependence on natural sun-drying is crucial for improving product consistency and market reliability. This includes investing in mechanical drying technologies, affordable drying facilities, and sanitary workstations. The need for standardized procedures for drying, washing, impurity removal, and salt reduction was often mentioned, as such protocols would help lower quality differences and meet export standards. Stakeholders also called for the development of storage, cooling, and pre-processing hubs to reduce the time between harvest, sorting, and transport—an important factor in preventing spoilage and maintaining product quality.

- **Development Needs in the Processing Stage**

Strengthening processing capacity has become one of the most widely shared priorities across the region. Respondents emphasized the need to expand the ability to produce hydrocolloid products such as agar, carrageenan, and alginate, as well as to extract functional compounds, including fucoidan and laminarin. Establishing regional processing hubs and shared processing facilities was seen as essential for enabling value addition, especially in economies that rely heavily on raw dried

seaweed exports. Support for international certifications—such as HACCP, GMP, ISO, and organic certification—was also considered important for gaining access to higher-value global markets. Many respondents stressed the need for stronger collaboration platforms that connect government, academia, and industry to speed up R&D and technology transfer.

- **Development Needs in Distribution and Trade**

Responses showed a widespread need for improved understanding of trade requirements, including international quality standards, traceability rules, and rules of origin. Stakeholders expressed a strong interest in creating an “APEC Seaweed Trade & Standards Hub” to consolidate and disseminate such information. Logistics-related needs were also prominent, including expanding cold-chain capacity and storage infrastructure to reduce distribution costs and maintain product quality. Digital marketplace tools to better connect producers with buyers, along with pricing information systems to promote transparency in raw material procurement, were also identified as valuable. Support for entering green markets—such as sustainability labelling, organic certification for cultured seaweed, and responsible sourcing schemes—was another recurring theme.

- **Development Needs in Governance and Institutional Systems**

Across economies, respondents pointed to the need for a more integrated governance framework that aligns policies across environment, aquaculture, trade, and spatial management. Strengthening producer organizations and cooperatives was viewed as vital for improving bargaining power, supporting collective marketing, and reducing dependence on intermediaries. Survey results also indicated broad demand for domestic seaweed development strategies, regulatory updates, and increased public investment in seaweed-related R&D. Many stakeholders emphasized that supply-chain transparency can be significantly enhanced through digital systems enabling traceability, data management, and real-time oversight from farm to final product.

# 4. Strengthening Climate Resilience and Food Security via Stakeholder-Driven Sustainable Seaweed Supply Chains

## 4.1. Strengthening Climate Resilience in the APEC Region

The seaweed industry in APEC economies spans a wide spectrum—from large raw-material suppliers to technologically advanced processors. This structural diversity shapes the region’s uneven capacity to respond to climate change. In lower-income economies such as Indonesia and the Philippines, farmers earning USD 440–590 per ton of dried seaweed face financial barriers to participating in climate initiatives, particularly carbon-credit schemes that require costly monitoring, reporting, and verification (MRV) processes (Lodhia & Shive, 2023; Kesling & McHugill, 2025).

Advanced processing economies also show systemic vulnerabilities. In the Republic of Korea, about 94.8% of seaweed output is concentrated in a single province, and three species—laver, kelp, and wakame—account for nearly 97% of production (Statistics Korea, 2024). This geographic and species concentration heightens exposure to heatwaves, cold-water anomalies, disease outbreaks, and

market volatility. Despite representing only one-third of production volume, laver generates roughly 85% of total seaweed value, increasing the industry's sensitivity to disruptions in a single commodity.

Scientific debate continues regarding seaweed's role in climate mitigation. The IPCC's upcoming AR7 cycle may refine methods for carbon removal, but seaweed is still not formally recognized as a carbon sink because of uncertainties around permanence, additionality, and ecological risks (IPCC, 2024). Although recent evidence suggests that sediments beneath seaweed farms can store carbon at levels comparable to mangroves (Duarte et al., 2025), economic feasibility remains limited. For example, The Nature Conservancy estimates that median net sequestration from farmed seaweed is only 0.5 t $CO_2$e per year—far below what farmers would need to benefit, requiring carbon prices of USD 300–500 per ton to raise incomes by even 10%.

More immediate mitigation potential lies in avoided emissions. Seaweed-based biofuels, bioplastics, and biochemicals can substitute fossil-fuel-derived materials without relying on land, freshwater, or fertilizers. The APEC Energy Working Group identifies bioplastics as a fast-growing opportunity that could be accelerated through targeted incentives (APEC Energy Working Group, 2025). In livestock systems, seaweed feed additives—particularly Asparagopsis taxiformis—have shown methane reductions of over 80% (Nelson, 2021), offering a practical decarbonization pathway.

Seaweed also plays a key role in ecosystem-based adaptation. Farms and natural kelp forests function as "living shorelines," reducing storm impacts and coastal erosion. Restoration activities in Korea, along with similar initiatives in California, highlight the importance of kelp recovery in enhancing coastal resilience under climate change.

Taken together, these findings point to three key priorities for enhancing climate resilience in the APEC seaweed sector:

- **Elevating avoided emissions as a central mitigation strategy**, supported by life-cycle assessment (LCA) methodologies and targeted fiscal incentives to promote biofuel, bioplastic, and methane-reduction feed applications.
- **Supporting scientific research and regional benefit-sharing mechanisms** to improve understanding of seaweed carbon dynamics and unlock future blue-carbon opportunities through voluntary carbon markets.
- **Integrating seaweed into National Adaptation Plans (NAPs)** across APEC economies to mainstream seaweed-based climate solutions—including coastal protection, sustainable farming systems, and low-carbon applications—into domestic climate policy frameworks.

These strategies collectively emphasize the need for coordinated regional action, evidence-based policymaking, and inclusive approaches that ensure all economies—particularly low-income coastal communities—can participate meaningfully in the transition toward climate-resilient seaweed systems.

- **Best Practice: Indonesia's Blue Carbon Governance and Japan Blue Carbon Credit**

The cases of Indonesia and Japan offer two distinct but highly complementary models for strengthening climate resilience and advancing sustainable seaweed systems within the APEC region. Each illustrates a different entry point—community-centered governance in Indonesia and science-based institutional certification in Japan—highlighting how diverse approaches can work together to build an inclusive

and robust blue carbon framework.

- **Indonesia: Community-Driven, Justice-Oriented Blue Carbon Governance**

Indonesia's recent blue carbon initiatives demonstrate how climate governance can be strengthened when coastal communities are placed at the center of decision-making (World Resources Institute, 2025). In Riau and West Nusa Tenggara, where mangroves and seagrass meadows provide ecosystem services worth millions of dollars annually, WRI Indonesia's pilot activities showcased that local participation in data collection and monitoring increases both accuracy and legitimacy. These pilots also revealed that social equity gaps—particularly for women fishers, gleaners, and youth—remain major barriers to accessing the benefits of conservation projects.

To address this, Indonesia has begun integrating Just Transition (JT) principles into blue carbon policy development. This includes:

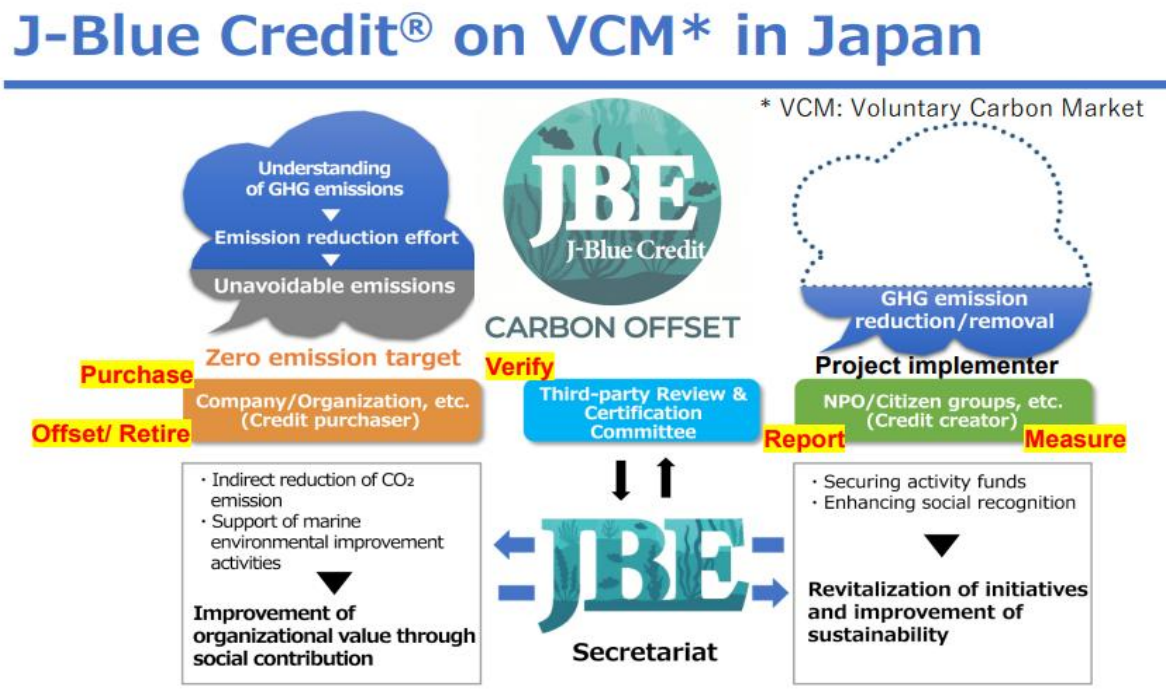
- **Distributive justice**, ensuring fair allocation of benefits from carbon and conservation projects.
- **Procedural justice**, enabling transparent and inclusive decision-making processes.
- **Recognition justice**, acknowledging the cultural, economic, and gender-specific roles of coastal communities.

These principles are now embedded within the economy's long-term domestic development strategy (RPJPN 2025–2045) and are reinforced through newly established blue carbon legal instruments, including the Ministerial Regulation on Ocean-Based Carbon Pricing and Presidential Regulation No. 110/2025 on the Carbon Economic Value (CEV) (Zaid, M et al., 2025). Together, these policies create the first comprehensive regulatory framework that formally recognizes blue carbon ecosystems within Indonesia's carbon market. The CEV framework enables carbon trading, results-based payments, and the registration of blue carbon projects, offering formal pathways for coastal ecosystems to contribute to— and benefit from—domestic climate mitigation efforts. Indonesia's decision to incorporate blue carbon ecosystems into its second Nationally Determined Contributions (NDCs) and the broader CEV system marks a significant shift toward linking marine ecosystems with domestic mitigation planning, carbon markets, and climate finance. This alignment enhances environmental integrity by strengthening greenhouse gas accounting and ensures that local communities are positioned to participate in, and benefit from, emerging blue carbon finance mechanisms (GGGI, 2025).

- **Japan: Scientifically-Rigorous Blue Carbon Certification via J-Blue Credit®**

Japan's **J-Blue Credit® scheme** presents a contrasting best practice anchored in strong institutional capacity, scientific research, and standardized MRV methodologies (Japan Blue Economy Association, 2025). Developed by the Ministry of the Environment and partner research institutes, the J-Blue system formalizes the values of carbon and ecosystem services for coastal restoration activities, such as seagrass and seaweed bed **rehabilitation.**

**Figure 1. J-Blue Credit® on the Voluntary Carbon Market in Japan**




Source: **Watanabe, A. (2025)**

Key features include:

- **Centralized development of scientific methodologies** for measuring carbon and ecological benefits.
- **Transparent certification procedures**, aligned with domestic climate policy frameworks.
- **Third-party verification mechanisms**, ensuring credibility for companies purchasing blue carbon credits.
- **Cost-reducing support systems**, allowing small-scale coastal groups and local governments to participate without bearing heavy MRV expenses.

Japan's experience demonstrates how a government-led certification system can stimulate private investment, expand restoration initiatives, and provide a predictable structure for scaling blue carbon markets.

## 4.2. Strengthening Food Security in the APEC Region

Seaweed is becoming one of the most strategic resources for strengthening food security across the APEC region. As economies face climate pressures, supply-chain disruptions, and resource constraints, seaweed offers a rare combination of nutritional density, ecological sustainability, and industrial versatility, making it a foundation for resilient food systems.

Nutritionally, seaweed provides high-quality proteins, complementary amino acids, and essential micronutrients—including iodine, iron, calcium, magnesium, and multiple vitamins—which are often lacking in low-income and coastal communities

(Thiviya et al., 2022). Bioactive compounds such as fucoidan, laminarin, and mannitol further support immune health. For vegetarian and climate-conscious consumers, seaweed offers nutrients difficult to obtain from land-based plants, strengthening population-level nutrition and resilience.

Environmentally, seaweed cultivation requires no freshwater, arable land, or synthetic fertilizers, positioning it among the most sustainable biomass sources. However, its heavy concentration in nearshore waters leaves current production vulnerable to marine heatwaves, pollution, storms, and harmful algal blooms—making diversification and more resilient farming systems essential.

Technological innovation plays a key role in building this resilience. Offshore farming, land-based tank culture, and integrated multi-trophic aquaculture (IMTA) offer more stable, controlled, and year-round production (Yang et al., 2025). Advances in strain improvement, seedstock quality, digital monitoring, and extension services can help close the productivity gap between small-scale and commercial farmers.

Beyond direct consumption, seaweed underpins global food-processing industries through hydrocolloids—carrageenan, agar, and alginate—used in stabilization, preservation, and texture modification. As functional foods and nutraceutical markets grow, their economic significance continues to rise.

For developing economies, industrial upgrading is essential. Moving from low-value dried exports to higher-value extracts enables stronger incomes, greater resilience, and more diversified food systems. Modern extraction techniques—such as supercritical $CO_2$, microwave-assisted extraction, and enzyme-based processes—support the development of high-value applications while allowing by-products to be reused for fertilizers, animal feed, or bioplastics (Hosny et al., 2025).

Seaweed also strengthens food security indirectly through its role in sustainable aquaculture and agriculture. Feed additives derived from seaweed enhance growth, immunity, and stress tolerance in farmed species, reducing fishmeal dependence (Jeon & Kim, 2015). Residual biomass can enrich soils and improve crop productivity, linking marine and terrestrial food systems.

- **Best Practice: Korea's Seaweed Aquaculture**

Korea represents one of the most advanced seaweed-based food-security and industrial-development models in the APEC region. As the world's third-largest producer, Korea harvests about 1.7 million tonnes annually—76.5% of its coastal aquaculture output—and cultivates the widest diversity of farmed seaweed species (FAO, 2025; KMI, 2024). More than ten commercial species, including laver, kelp, wakame, Sargassum, Hizikia, green laver, and sea mustard, demonstrate a highly diversified and technologically mature aquaculture system.

Korea's greatest achievement is the transformation of **laver (Pyropia spp.)** into a USD 1-billion global export industry. A specialized value chain—seed production, farming, dried-laver processing, seasoned-laver manufacturing, and export logistics—enabled Korea to scale the industry and export to 124 economies. The global rise of K-Food helped position laver as a premium, health-oriented snack.

This success was driven by decades of innovation. Artificial seed production in the 1960s ended reliance on natural spore settlement. Synthetic nets, offshore longline systems, conchocelis culture control, and mechanized drying (1970s–80s) increased efficiency and stability. Since the 2010s, the Plant Variety Protection (PVP) system expanded breeding programs that now supply over 95% of domestic seedstock with heat-tolerant and disease-resistant cultivars, helping the industry adapt to climate variability.

Institutional frameworks further strengthened competitiveness. Korea's Laver Industry Development Plan supports sustainable supply chains and global branding (MOF, 2023). The Aquatic Seed Industry Promotion Act and Plant Variety Protection Act ensure high-quality seed governance. Adoption of MSC/ASC certification has enhanced traceability and opened access to premium markets in Europe; Japan; and the United States. Korea's aquaculture insurance system mitigates losses from typhoons, red tides, and marine heatwaves, reducing climate-related risks.

## 4.3. Implication for APEC Economies

Drawing from the complementary approaches of Indonesia and Japan, several strategic implications emerge for APEC economies working to strengthen climate resilience and build sustainable seaweed-based systems.

- **Socially Inclusive and Legally Grounded Blue-Carbon Governance**

  Indonesia's experience shows that blue-carbon policies work best when coastal communities—including women, youth, and small-scale farmers—are active participants in monitoring and decision-making. Embedding Just Transition principles helps ensure that climate actions do not reinforce inequality. Indonesia has further strengthened this approach through new legal frameworks, including the Carbon Economic Value (CEV) regulation and the ocean-based carbon-pricing system, demonstrating how inclusive engagement and clear regulatory foundations together enhance the effectiveness and fairness of blue-carbon initiatives.

- **Scientific rigor and standardized MRV frameworks are essential to unlock climate finance**
  Japan's J-Blue Credit® demonstrates how credible methodologies, transparent certification, and centralized MRV systems can reduce transaction costs for small producers and attract private-sector investment. APEC economies can adapt this model by establishing domestic MRV platforms, technical support hubs, and clear guidelines that enable broader participation in carbon and environmental credit markets.

- **Lowering barriers for small-scale and low-income actors is critical for regional resilience**
  Many producers in APEC economies lack the resources to join carbon-credit schemes or climate-finance programs due to high monitoring and certification costs. Shared regional methodologies, simplified verification procedures, and pooled financing mechanisms could help reduce these barriers.

- **Diversification reduces vulnerability to climate shocks**
  Species diversification, climate-resilient farming technologies, and improved seed systems are essential to reduce risks associated with geographic concentration and monoculture. These measures can support both environmental and economic resilience across producer communities.

- **Integrating seaweed into domestic climate frameworks strengthens policy coherence**
  APEC members should consider incorporating seaweed farming, coastal habitat restoration, and avoided-emissions pathways into National Adaptation Plans (NAPs) and upcoming NDC updates. This formal recognition can help mobilize funding, institutional support, and long-term planning for seaweed-based solutions.

- **Regional cooperation can accelerate learning and scale impacts** APEC is well-positioned to facilitate harmonized methodologies, shared scientific research, blue-carbon data platforms, and joint financing initiatives. Such cooperation can significantly reduce the resource gaps between economies and support inclusive participation in future climate-resilient seaweed systems

Building on the analysis above and the case of Korea, several actionable implications emerge for APEC economies seeking to enhance food security through sustainable and climate-resilient seaweed systems. These implications highlight how technological innovation, institutional frameworks, and value-chain upgrading can be designed to fit diverse domestic contexts while supporting regional cooperation.

- **Diversified and climate-resilient production systems are essential for long-term food security.** APEC economies can reduce vulnerability to climate shocks by expanding species portfolios, investing in selective breeding, and transitioning from nearshore dependency toward offshore, land-based, and IMTA (Integrated Multi-Trophic Aquaculture) systems. Korea's success with heat-tolerant and disease-resistant Pyropia cultivars demonstrates the importance of sustained R&D and variety protection.

- **Strong seed governance systems underpin stable seaweed supply chains.** The establishment of economy's seed banks, certification systems, and variety-protection mechanisms can help ensure consistent seed quality and reduce market disruptions—an approach APEC member can adapt from Korea's Aquatic Seed Industry Promotion Act and PVP framework.

- **Upgrading from raw-material exports to high-value processing strengthens economic resilience.** Most APEC coastal communities still export raw dried seaweed at low margins. By investing in processing infrastructure, extraction technologies, and product diversification (hydrocolloids, nutraceuticals, functional foods), economies can capture greater value while improving food-system stability.

- **Integrating seaweed into domestic food-security and nutrition strategies expands societal benefits.** Seaweed's micronutrient richness and bioactive compounds provide a cost-effective pathway for improving public health in low-income coastal populations. APEC economies can incorporate seaweed into school feeding programs, economy-wise dietary guidelines, and community nutrition initiatives.

- **Climate-risk management tools enhance stability for producers.** Korea's aquaculture insurance model—covering typhoons, red tides, and marine heatwaves—offers a transferable framework that other APEC economies could adapt, especially island and archipelagic economies with high climate exposure.

- **Sustainability certification and traceability improve global market access.** Expanding adoption of ASC/MSC and other sustainability labeling can help APEC producers enter premium markets. Digital traceability systems also build consumer trust and align with emerging global trade requirements.

- **Regional cooperation accelerates innovation and reduces disparities.** APEC can play a convening role by harmonizing breeding standards, sharing disease-management protocols, coordinating blue-carbon and avoided-emission methodologies, and mobilizing joint research funds to support smaller economies.

# 5. Conclusion

This report explores the growing significance of seaweed as a strategic resource for climate resilience, food and nutrition security, and high-value industry development across the APEC region. By analyzing regional production trends, supply-chain vulnerabilities, climate risks, and gaps in technology and institutions, the report affirms that seaweed is no longer just a niche coastal commodity but a core sector with the potential to support domestic and regional sustainability objectives. The findings emphasize that APEC economies collectively produce most of the world's seaweed. However, the sector faces ongoing structural challenges: climate-related production instability, heavy concentration in certain regions and species, uneven processing and R&D capacities, limited market access for small-scale farmers, and the lack of harmonized MRV and certification systems. Addressing these issues is crucial for enhancing regional resilience, maintaining stable food systems, and creating new economic opportunities.

The case studies—Indonesia's community-focused blue carbon governance, Japan's scientifically robust J-Blue Credit® system, and Korea's laver industry—illustrate different approaches to advancing sustainable seaweed development. Indonesia shows how social inclusion, local participation, and justice-oriented governance improve the legitimacy and durability of climate and restoration efforts. Japan offers a model for developing standardized, transparent, and cost-effective MRV frameworks that can attract private investment and scale up restoration initiatives. Korea demonstrates how technological innovation, value-chain specialization, and strong institutional support can turn seaweed into a high-value export industry that directly supports domestic food security.

Together, these cases highlight that the future of seaweed in APEC depends on balancing scientific accuracy with social fairness, combining advanced technology with community-driven methods, and aligning domestic policies with regional cooperation. Strengthening climate-resilient production systems, expanding high-value processing industries, integrating seaweed into National Adaptation Plans and NDC updates, and harmonizing regional standards will be vital steps.

In the end, seaweed presents APEC economies with a unique chance to improve food and nutrition security, restore marine ecosystems, lower emissions, and develop inclusive coastal economies. By sharing knowledge, coordinating policies, and fostering cross-economy collaboration, APEC can lead the global shift toward a resilient, low-carbon, and sustainable seaweed-based future.

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