Capability gaps also appear in the ability to respond to biotic and abiotic stressors. Seaweed yield is highly sensitive to temperature, salinity, light, nutrient availability, pests, and disease, so farms with weaker monitoring and management capacity are less able to maintain stable output under changing conditions (Khan et al., 2024). Reviews further emphasize that careful site selection, development of disease-resistant strains, and improved mitigation strategies are essential for overcoming these pressures, which means disparities in management competence directly translate into disparities in green-farming performance (Khan et al., 2024).

7.3 Need for improvement in market mechanisms and policy support systems

Green *Porphyra* farming also faces a structural challenge in that market mechanisms often do not fully reward ecological performance. Seaweed aquaculture delivers ecosystem services such as climate mitigation, eutrophication control, and circular-bioeconomy benefits, but these benefits do not automatically translate into farm-level returns unless value chains, product markets, and institutional incentives are aligned (Duarte et al., 2021). Even when seaweed farming is environmentally cost-effective, long-term industry growth still requires rising demand, output diversification, and some form of compensation or policy recognition for nutrient-removal services (Khan et al., 2024).

Policy support systems also remain incomplete relative to the scale of transformation required. Efficiency analyses of China's seaweed sector indicate that green development has improved, but significant regional disparities persist and future progress depends on technology innovation, structural optimization, carbon-sink trading policy, and specialized talent development (Le and Wei, 2023). At the global level, sustainable aquaculture roadmaps similarly stress stronger governance, regulatory frameworks, research investment, and planning integration, indicating that green *Porphyra* farming will advance fastest where market design and public policy evolve together rather than separately (Mair et al., 2023).

8 Conclusions and Future Outlook

Overall, green *Porphyra* farming models have shown clear application value because they combine biomass production with measurable ecological services. Open-sea cultivation of *P. yezoensis* significantly reduced dissolved inorganic nitrogen and phosphorus, demonstrating that nori farming can function as an effective bioremediation system in eutrophic coastal waters. At the broader seaweed-aquaculture level, seaweed farming is recognized as a nature-based pathway for climate mitigation, eutrophication control, and circular bioeconomy development, which reinforces the strategic value of green *Porphyra* models beyond simple yield enhancement.

The effectiveness of these models is also reflected in their contribution to carbon-related ecosystem functions, although the strength of evidence differs by mechanism. Recent field evidence shows that *Porphyra* cultivation increased dissolved organic carbon and promoted refractory dissolved organic matter formation, indicating a positive role in coastal carbon sequestration processes. At the same time, national-scale analysis in China found that seaweed cultivation has already generated substantial CO_2-emission reduction and blue-carbon benefits, supporting the view that green nori farming should be evaluated as part of a larger low-carbon mariculture transition rather than as an isolated farm technology.

Future progress in green *Porphyra* farming will depend first on strengthening breeding and production-control technologies. Across seaweed aquaculture, breeding and genetic improvement are identified as priorities for developing strains that are more productive, stress resistant, and better suited to climate change, while recent reviews also point to tissue culture, selective breeding, and gene-editing approaches as promising tools to improve yield, stress tolerance, and biochemical traits. For *Porphyra* specifically, this direction is important because strain performance under warming, nutrient fluctuation, and disease pressure will increasingly determine the real effectiveness of green farming systems.

A second technology direction is the integration of intelligent monitoring, automation, and advanced environmental management. Reviews of seaweed farming emphasize automated cultivation and harvesting systems as a route to higher efficiency and lower cost, while Industry 4.0 analyses show that digitalization is becoming a core pathway