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The Impact of Environmental Regulation and International Trade Rule Coordination on Corporate Innovation

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Abstract. Based on environmental and international trade data from 40 countries, this study constructs a Policy Synergy Index for environmental regulations and international trade rules. Using regression models, it examines the synergistic impact of these regulations on corporate innovation. Findings reveal a measurable synergistic effect, primarily manifested as a linear relationship between the synergy index and patent output. From a governmental perspective, the paper proposes: (1) establishing an international coordination mechanism through multilateral platforms like the WTO to advance mutual recognition of carbon tariffs, green technology standards, and environmental goods lists, thereby reducing corporate dual compliance costs; (2) implementing innovation-oriented policies that dynamically link the Environment-Trade Synergy Index with tax incentives, while creating a cross-border green technology transfer fund to accelerate innovation diffusion. Tiered policy tools should target developed countries (technical standard mutual recognition), emerging economies (compliance capacity building), and least-developed countries (green assistance). Progress should be monitored through a globally unified accounting system for synergy indices. Governments must pre-assess policy international compatibility, while enterprises should strengthen full-chain compliance management, ultimately achieving dual wins in green trade expansion and global carbon emission reduction.

Keywords: Environmental regulation, Corporate innovation, Coupled co scheduling

1. Introduction

With the promotion of the Paris Agreement and the rise of trade rules such as carbon border regulation mechanism, enterprises are not only facing the constraints of domestic environmental policies, but also facing the challenges of green barriers in international markets. Under the dual pressure of global climate change and sustainable development goals, the synergy between environmental regulation and international trade rules has gradually become an important issue in the economic transformation of various countries. How the policy interaction between environmental regulation and international trade rules affects the innovation behavior of enterprises is not only the focus of theoretical research, but also a practical problem that needs to be solved urgently in policy practice.

As enterprises respond to environmental regulation by optimizing product structure [1], the strengthening of environmental regulation is usually regarded as one of the driving forces to

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promote enterprise innovation. However, some studies have found that different environmental regulation tools have the opposite effect on enterprises. When the resource base of enterprises is strong, the "forced" effect of pollution charges on green innovation is more obvious, but this phenomenon does not exist in environmental subsidies. Pollution charges promote the output of green invention patent achievements of enterprises, while environmental subsidies "crowd out" the output of green invention patents and green utility model patents of enterprises [2].

With the strengthening of the impact of international trade rules on the production and operation activities of enterprises, studies began to discuss the impact of trade policies on enterprise innovation. Some scholars have found that green trade barriers can promote enterprises to occupy the resources of green technology innovation while increasing investment in green technology transformation [3].

To a certain extent, the intervention of international trade rules conflicts with domestic environmental policies, which may weaken the effect of policies on enterprise innovation, leading enterprises to fall into the dilemma of "rising compliance costs insufficient innovation momentum". Existing research predominantly examines the impact of environmental regulations or international trade rules on corporate innovation in isolation. However, the synergistic policy mechanisms between these two domains remain underexplored, particularly regarding the construction of a quantifiable policy synergy index. This gap hinders a systematic analysis of how environmental regulations and international trade rules, through complementary or conflicting dynamics, shape corporate innovation pathways. To address this, the present study constructs a policy synergy index for environmental regulations and international trade rules. Subsequently, employing regression analysis, it investigates the synergistic effects of these combined policies on corporate innovation

The research of this paper has important theoretical and practical significance for micro enterprise innovation. Theoretically, the existing literature has debated Porter's hypothesis and cost effect. Some scholars have proposed that environmental regulation has a significant threshold effect on enterprise innovation. When the level of economic development is low, the impact of cost effect on the innovation level of enterprises is more obvious. However, if the intensity of environmental regulation exceeds a certain threshold/threshold, the effect of innovation compensation is dominant [4]. The integration of international trade rules introduces mediating complexity into the relationship between environmental regulation and corporate innovation. Specifically, under stringent environmental regimes, foreign direct investment (FDI) can temporarily enhance green innovation capabilities in select firms via technology transfer mechanisms [5]. However, in jurisdictions with lax environmental regulations, this dynamic may induce a pollution haven effect—where multinational enterprises relocate highly pollutive and energy-intensive industries to circumvent stringent domestic environmental standards. Such industrial transfers directly exacerbate environmental degradation, ecological damage, and public health risks. Consequently, elucidating the policy synergy mechanism between environmental regulations and international trade rules is critical for reconciling theoretical divergences and informing effective governance.

From a practical point of view, China's "double carbon" goal and the promotion of "one belt and one road" investment require policymakers to balance the intensity of environmental regulation with international trade competitiveness. First of all, from the perspective of enterprises, Chinese enterprises are facing the pressure of international trade policies such as high-intensity EU carbon tariffs and technological transformation and upgrading, so that enterprises may lose innovation momentum due to dual compliance costs. In addition, from the government level, the contradiction between the upgrading of domestic environmental regulation and the lack of coordination of

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international green trade rules is becoming prominent. On the one hand, domestic carbon emission trading market, green supply chain standards and other policies need to accelerate international integration. On the other hand, lower environmental regulatory stringency in certain Belt and Road economies raises concerns that strict adherence to domestic standards may compromise project economic viability.

Therefore, the study of policy synergy between environmental regulation and international trade rules is of great significance to enterprises and policymakers.

The research contents of this paper are as follows:

This study first examines the innovation-inducing mechanisms through which environmental regulations and international rules compel corporate innovation, analyzing conflict-coordination dynamics between international environmental agreements and trade frameworks while incorporating domestic-international policy interactions. Subsequently, a policy synergy index is constructed by: (1) decomposing environmental regulations and trade rules into discrete dimensions; (2) calculating dimension weights via the entropy method, and implementing two-dimensional synergy assessment using a coupling coordination model. Finally, regression analysis incorporating robustness checks quantifies the index's impact on corporate patent output.

2. Impact mechanism

2.1. Conflict and coordination

In the context of frequent environmental problems in the new century, all countries have formulated or implemented relevant environmental regulations. Substantial cross-national heterogeneity in environmental governance has precipitated a proliferation of environmental regulations as ecological challenges intensify. This regulatory expansion increasingly generates normative conflicts with established international trade frameworks. For example, there are double standards between some discriminatory environmental measures and most favored nation treatment stipulated by the WTO, and enterprises actually increase the cost of compliance when meeting the double standards. In addition, international environmental agreements tax according to carbon emission intensity, which is also different from WTO regulations. Policy differentiation manifests primarily through divergent regulatory objectives, wherein international environmental agreements—operationalizing the 'Common but Differentiated Responsibilities' (CBDR) principle—legitimize differential carbon pricing mechanisms for high-emission products across jurisdictions. WTO rules require members to abide by national treatment and most favored nation treatment, and prohibit differentiated trade restrictions based on the intensity of carbon emissions from production processes. Because of this differentiation, companies are forced to adjust production processes. Therefore, under many differentiated standards of environmental regulation and international trade rules, enterprises inevitably need to use innovation to improve their production or product standards to comply with international rules.

2.2. The interaction between domestic policies and international rules forces enterprises to innovate

The essence of rule conflict is the embodiment of the fragmentation of global governance, but it also provides strategic opportunities for enterprise innovation. Environmental regulation and international trade rules force enterprises to innovate, and actually construct a three-step progressive logic of "pressure transformation capability transition pattern reconstruction". Its core is to reveal

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the co evolution mechanism of micro enterprise strategy and macro policy tools under the dual constraints of environmental regulation and market competition. The specific logic can be disassembled into three closed-loop levels:

1. Micro transmission logic: enterprises internalize external pressure into innovation momentum (compliance → innovation). Due to the rising cost of environmental compliance, enterprises are forced to reconstruct production function and strive for green technology breakthroughs through increasing investment in technology research and development. Enterprises use environmental regulation to stimulate innovation compensation effect, offset compliance costs by improving resource utilization efficiency, and form an "innovation offset" mechanism.

2. Meso strengthening logic: transforming innovative achievements into competitive advantages (innovation → competitiveness) and using technological innovation can not only reduce costs for cost reconstruction, but also transform technological advantages into the voice of industry standards.

3. At the macro-structural level, enhancing firm-level competitive advantages triggers dual dynamics: industrial pattern realignment through market selection mechanisms, and the emergence of self-reinforcing innovation feedback loops that accelerate technological frontier advancement. When the competitiveness of the industry is improved, the state can further use policy tools to reconstruct the industrial chain. For example, the United States stipulates that the value ratio of key minerals in batteries (lithium, cobalt, graphite, nickel, manganese, etc.) needs to come from the United States or countries with which it has signed a free trade agreement (FTA), or recycled in North America to restrict market access, forcing multinationals to adjust the geographical layout of supply chains. Feedback mechanism refers to that when the competitiveness of enterprises is improved, it will enhance the confidence of policymakers in regulation, so as to introduce higher intensity environmental regulation and form a new round of innovation incentives. The essence of this "regulation innovation" spiral mechanism is the embodiment of Schumpeter's "creative destruction" theory in the green transformation scenario.

Through the closed-loop of "compliance innovation competitiveness", regulation forces enterprises to transform external pressure into technological breakthrough power and improve their competitiveness. On the one hand, compliance pressure drives supply chain upgrading. Based on specific data, scholars have found that government environmental regulations significantly improve the quality of export products to promote enterprise innovation [6]. On the other hand, policy coordination guides the direction of innovation, such as enterprises accelerating the research and development of solid state batteries through special policy support to seize the international market.

2.3. Impact of policy synergy on enterprise competitiveness and innovation direction

2.3.1. Mechanisms to enhance international competitiveness

The international competitiveness enhancement mechanism operates through dual channels: market-access privileges whereby environmentally certified enterprises obtain preferential entry to stringent regulatory markets; and strategic premium pricing enabled by ESG-compliant branding that captures sustainability-driven consumer surplus.

2.3.2. Government strategic guidance in innovation direction

On the one hand, with the promulgation of new policies, policy funds are inclined to clean energy from the focus of technological path. On the other hand, the government guides the establishment of

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green supply chain alliances, upstream and downstream enterprises share technical standards, and reduce R&D costs.

3. Build policy synergy index

3.1. Index selection and data source

In the construction of measurement indicators, the synergy index should reflect the dynamic relationship between the two promoting or restricting each other, and should take into account the consistency of policy objectives and the complementarity of implementation effects. This paper selects 40 countries around the world and obtains the data from 2018-2023 to construct the policy synergy index of environmental regulation and international trade rules.

The degree to which the government restricts the environmental behavior of enterprises through laws and economic tools is called the intensity of environmental regulation. In this paper, the environmental policy strictness index is selected to reflect the legal strictness of environmental regulation, the carbon tax rate (US dollar/ton CO_2) and the per capita environmental protection tax rate are selected to reflect the strength of economic tools of environmental regulation, and the environmental protection investment of various countries is selected to reflect the implementation of environmental regulation in various countries. The data on the intensity of environmental regulation in this paper are from the OECD.

In order to reflect the liberalization level of a country's participation in international trade, this paper obtains the average most favored nation tariff rate from the world bank to reflect the tariff level of each country, using the proportion of total imports and exports to GDP to reflect the degree of trade freedom, this paper obtains the number of technical trade measures (TBT) and anti-dumping measures from the WTO to reflect the level of non-tariff barriers of each country.

Table 1. Index selection and data sources

Category	Dimension	Specific Indicator	Data Source
Environmental Regulation Intensity Sub Index	Legal Stringency	Environmental Policy Stringency Index	OECD
	Economic Tool Intensity	Carbon Tax Rate (US $/ton CO_2), Per Capita Environmental Protection Tax	OECD
	Implementation	Environmental Protection Investment	OECD
Trade Openness Sub Indicator	Tariff Level	Average Most Favored Nation Tariff Rate	WORLD BANK GROUP
	Nontariff Barriers	Number of Technical Trade Measures (TBT) and Anti-Dumping Measures	WORLD BANK GROUP
	Trade Freedom	Total imports and exports as a share of GDP	WORLD BANK GROUP

3.2. Construction path

3.2.1. Data processing

In view of the differences in the dimension and magnitude of indicators, in order to ensure the comparability and aggregation of multi-source heterogeneous data and accurately quantify the

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dynamic synergy between environmental regulation and international trade rules, this paper standardizes the data, as shown in formula (1) to (2):

Positive Indicators

$$x_{ij}^{'} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \tag{1}$$

Reverse Index

$$x_{ij}^{'} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \tag{2}$$

where the subscript i represents the serial number of the data sample (observation object), that is, the individual country in the study. The subscript j represents each indicator, which corresponds to the specific indicators of environmental regulation or international trade rules (for example, j=1 is the environmental policy strictness index). Where x_{ij} is the original value of the i-th country on the j -th indicator, $min(x_j)$ is the minimum value of the j-th indicator in all 40 countries, $max\,(x_j)$ is the maximum value of the j-th indicator in all 40 countries, and $x_{ij}^{'}$ prime is the non-dimensional value of the i-th country on the j-th indicator after standardization.

3.2.2. Weight determination

To mitigate multicollinearity risks among indicators while preserving variable independence and eliminating redundant weighting effects, the entropy method is employed to derive objective weights commensurate with data dispersion patterns—thereby establishing a robust foundation for model specification. The specific method is shown in formula (3) (4):

$$E_j = -\sum p_{ij} \ln p_{ij} \tag{3}$$

$$\omega_j = \frac{1 - E_j}{\sum(1 - E_j)} \tag{4}$$

where i refers to the country number, j refers to the index number, and p_{ij} refers to the probability value of the i-th country on the j-th index. The calculation method is $p_{ij} = \frac{x_{ij}^{'}}{\sum_{i=1}^{40} x_{ij}^{'}}$ refers to the information entropy of j index. The more the entropy, the greater the data variation. ω_j represents the weight of the j -th indicator, which meets the requirements of $\sum \omega_j = 1$.

3.2.3. Calculate the sub system index

In order to directly reflect the comprehensive level of each sub system, the weighted sum is used to calculate the sub system index, as shown in formula (5) (6):

$$ERI = \sum_{j=1}^{n} \omega_j \bullet x_{ij}^{'} \tag{5}$$

$$TOI = \sum_{j=1}^{m} \omega_K \bullet x_{ij}'$$

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(6)

where i refers to the country number, j refers to the index number, n and m are the number of indicators of the environmental regulation sub system and the trade openness sub system, ERI is the environmental regulation intensity index, and TOI is the trade openness index.

3.2.4. Building synergy model

Based on the theory of system synergy, the interaction and overall coordination level of two subsystems (environmental regulation and international trade rules) are quantified by using the coupling coordination model widely used in the fields of ecological economy and regional coordination. Coupling (C) measures the degree of interdependence between the two systems and reflects the dynamic correlation between policy tools. Coordination (D) is the comprehensive coupling degree and system development level (T) to avoid misjudgment of low level coupling as high synergy. As shown in formula (7) (8) (9):

$$C = \sqrt{\frac{ERI \bullet TOI}{(\frac{ERI+TOI}{2})^2}} \tag{7}$$

$$\mathrm{D} = \sqrt{\mathrm{C} \bullet \mathrm{T}} \tag{8}$$

$$\mathrm{T} = \alpha \mathrm{ERI} + \beta \mathrm{TOI}\,(\alpha + \beta = 1, \alpha = \beta = 0.5) \tag{9}$$

α and β weight parameters, default equal weight (0.5 each), assuming that environmental regulation and trade opening contribute equally to synergy, so as to balance the absolute level of the two systems and avoid low level coupling and virtual high coordination scheduling.

Drawing lessons from previous studies [7], the degree of coupling coordination is divided into ten levels: extreme disorder (0.0.1), severe disorder [0.1, 0.2), moderate disorder [0.2, 0.3), mild disorder [0.3, 0.4), verging disorder [0.4, 0.5), reluctant synergy [0.5, 0.6), primary synergy [0.6, 0.7), intermediate synergy [0.7, 0.8), good synergy [0.8, 0.9) and high-quality synergy [0.9, 1].

According to the above criteria, after calculating the specific synergy index of 40 countries with the data obtained, the following table (Table 2) is obtained:

Table 2. Specific synergy index of forty countries in the world in 2023

Country	D	Country	D	Country	D	Country	D
Denmark	0.87	Belgium	0.84	Portugal	0.79	Israel	0.64
Netherlands	0.87	Germany	0.84	Japan	0.77	China	0.63
Slovenia	0.87	Sweden	0.83	Spain	0.77	India	0.60
Italy	0.86	poland	0.82	Iceland	0.75	Luxembourg	0.59
Finland	0.86	Ireland	0.82	Korea	0.74	Russia	0.58
France	0.85	Greece	0.82	Canada	0.73	Mexico	0.57
Norway	0.85	Britain	0.81	Australia	0.68	Indonesia	0.54
Estonia	0.85	Slovakia	0.81	turkey	0.68	South Africa	0.54
Switzerland	0.85	Czech Republic	0.80	Chile	0.65	United States	0.52
Austria	0.85	Hungary	0.79	New Zealand	0.65	Brazil	0.23

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As shown in table 2, nearly half of the surveyed countries are in good coordination, and these 19 countries are all located in Europe, with only four countries being underdeveloped. Sixteen countries (the other three being the United Kingdom, Norway, and Switzerland) are part of the European Union, which implements a customs union and a common foreign trade policy due to a series of common policies and measures implemented by the European Community. In addition, the Environment Directorate General of the European Commission is responsible for formulating environmental policies and monitoring the implementation of these policies by member states. From this perspective, the series of environmental protection policies formulated by the European Union are well coordinated with international trade policies.

Seven countries each belong to intermediate and primary coordination, six countries are barely coordinated, and only one country (Brazil) is moderately imbalanced. According to the obtained data, Brazil's environmental policy strictness index is at a low level, but its tariff level ranks first among these forty countries. Therefore, it can be concluded that its high tariffs and low environmental regulation intensity are important reasons for its low synergy index.

4. Regression analysis and directions for improvement

4.1. Regression analysis

The policy synergy index (X) of environmental regulations and international trade rules obtained in this article and the number of patents per million population (Y) are panel data. During the data processing stage, there is usually a skewed distribution of patent numbers, and direct OLS may lead to heteroscedasticity. This article describes and statistically observes the skewness and kurtosis of Y by grouping by year.

Table 3. Skewness and kurtosis of patents per million population from 2018 to 2023

Year	Skewness	Kurtosis
2018	3.472690	16.72724
2019	3.498073	16.95375
2020	3.520391	17.15607
2021	3.444372	16.51915
2022	3.218659	14.63522
2023	3.063614	13.40154
All	3.388559	16.11220

According to the analysis in table 3, the skewness of all years is positive and the values are relatively large (all greater than 3), indicating that the distribution of variable Y is right-handed (positively biased). This means that there is a long tail on the right side of the data distribution, indicating the presence of many high-value (high patent count) outliers. Kurtosis is an indicator of the steepness of data distribution. Given that the kurtosis of a normal distribution is 3, and the kurtosis of all years in the table is much greater than 3, indicating that the data distribution has the characteristic of a sharp and thick tail. The data is more concentrated near the mean, and the tail is thicker (with more outliers). The right skewed distribution of patent numbers reflects the highly uneven nature of global innovation activities, with a few countries dominating global innovation output.

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Table 4. Skewness and kurtosis of the number of patents per million population after logarithmic transformation from 2018 to 2023

Year	Skewness	Kurtosis
2018	-0.730922	3.567796
2019	-0.744347	3.689321
2020	-0.766684	3.702194
2021	-0.756323	3.511468
2022	-0.767118	3.360822
2023	-0.797256	3.589139
All	-0.765061	3.575172

As shown in the table 4, in order to solve the serious right bias of patent data (original bias=3.39), we use log (y+1) for transformation. After transformation, the skewness dropped to - 0.77, the kurtosis dropped to 3.58, and the distribution was close to normal (the absolute value of skewness in each year was less than 0.8). Although there are slight low peaks, considering the robustness of the linear model, we use the fixed effect model.

Table 5 compared with time, country and two-way fixed effect:

Table 5. Impact of policy synergy index of environmental regulation and trade regulations on Enterprise Innovation

Variable	Enterprise Innovation	Enterprise Innovation	Enterprise Innovation	Enterprise Innovation
Policy Synergy Index	3.0974	-0.0659	3.1207	0.2706
	(0.8481)	(1.2196)	(0.8091)	(1.4396)
Fixed Year Effect	NO	YES	NO	YES
Country Year Fixed Effect	NO	NO	YES	YES
Observations	240	240	240	240
Adjusted R Squared	0.491	0.959	0.03	0.959

According to the above results, under the unfixed year effect results, the adjusted decisive coefficient is relatively small, indicating that the goodness of fit of the regression model is not good. Under the operation of only fixed year effect, the coefficient of synergy index between environmental regulation and international trade regulations does not conform to economic significance. Therefore, the regression model with the best fitting degree among the four sets of regression models, and each coefficient conforms to the economic meaning, is the year and country double fixed effect model:

$$Y = 4.590 + 0.27X + \varepsilon$$

$$R^2 = 0.967 \qquad \bar{R}^2 = 0.959 \qquad F = 0$$

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According to the results of the above formula, for every 100 units of synergy index, the number of patents per million people will increase by about 27.

4.2. Direction for improvement

The core research content of this paper is to explore the impact of environmental regulation and international trade rules on enterprise innovation. It should be pointed out that enterprise innovation decision-making itself is a complex process, which is deeply affected by R&D capabilities, human resources, organizational structure, strategic orientation and other internal factors. Unfortunately, this study failed to effectively control these important internal variables, which constitutes a significant limitation of this study.

5. Conclusion

Against the dual pressures of global climate change and sustainable development goals, this study examines how the policy interaction between environmental regulation and international trade rules influences corporate innovation behavior. Utilizing data from forty countries spanning 2018–2023, we employed the entropy weight method to calculate indicator weights and subsequently applied a coupling coordination degree model to derive a policy synergy index. The results indicate that the European Union's suite of environmental protection policies and international trade policies exhibit strong synergy. Conversely, a minority of countries demonstrate low synergy indices, attributable to their high tariffs coupled with weak environmental regulation intensity. Finally, regression analysis using the derived policy synergy index reveals that the synergistic effect of environmental regulation and international trade rules exerts a positive impact on corporate patent output.

Advancing the deep integration of environmental regulation and international trade governance requires establishing a comprehensive policy framework balancing environmental protection, trade liberalization, and innovation incentives. This necessitates resolving normative conflicts through multilateral coordination, institutional innovation, and differentiated strategies to catalyze green transformation. Using the WTO as the primary platform, climate goals from the Paris Agreement should be integrated with multilateral trade rules. A Collaborative Working Group on Environment-Trade Policy under the WTO's CTE should mediate conflicts involving carbon border adjustments, green tech standards, and non-discrimination principles, while a dynamic exemption list allows developing countries phased adoption of transitional environmental standards. Leveraging ISO to create a unified global environmental technical specification system is critical to reduce cross-border compliance costs and mitigate the crowding-out effect of multiple certifications on R&D. Nations should implement pre-legislative two-dimensional stress tests—vertically assessing carbon pricing's impact on export competitiveness and horizontally modeling major trading partners' policy shifts—to design adaptive transition clauses. Given heterogeneous capacities, a differentiated intervention framework is needed: deploying World Bank-funded Digital Compliance Capacity projects with satellite monitoring for emerging economies and Green Aid Plans for LDCs. UNCTAD should concurrently establish a Global Synergy Index and publish an annual Global Environment-Trade Synergy Development Report. Governments must develop policy impact simulation platforms to quantify regulatory effects on competitiveness, while enterprises build full-chain compliance systems with dynamic databases covering 142 jurisdictions. This collaboration fosters a "regulation-driven innovation → trade diffusion of standards → international rule convergence" cycle, achieving dual goals of increased green trade and global carbon reduction.

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