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Research on the cooperative network game model of marine plastic waste management

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ABSTRACT

Marine plastic waste pollution damages the stability of the marine ecosystem and inhibits the sustainable development of the "blue economy", which has aroused widespread concern worldwide. Nowadays, cooperation on marine plastic waste management is an urgent research topic. A global consensus on management cooperation is emerging, but the economic feasibility of cooperation has not yet to be proven. This paper takes the amount of capital investment, technology level of governance and the amount of marine plastic waste to be treated as variables affecting the cooperative income to construct a cooperative network game model for marine plastic waste management from the perspective of economics. The paper distributes benefits based on the "Myerson value", analyzes the equilibrium conditions of the model and tests the stability of cooperation. In addition, numerical analysis is carried out using actual data from key countries to demonstrate the practical economic feasibility of cooperation in marine plastic waste management. The findings include: (1) The technology level of governance and the amount of marine plastic waste to be treated have a negative impact on the country's choice of cooperative governance strategies and the stability of cooperative alliance, while the amount of capital investment is conductive to it. (2) The size of the alliance has an impact on country's strategic choices and the stability of the alliances. Too small an alliance is not conducive to cooperative alliance building, which gradually becomes more likely as the size of the alliance increases, but it is uncertain the effect of oversized alliance and what size is most appropriate. (3) Cooperation in marine plastic waste management is economically feasible at both the theoretical and practical levels. (4) Encouraging technological innovation to improve the governance level, implementing extended producer responsibility measures to shift the management cost, exerting the positive influence of key countries to promote the stability of the alliance, and establishing a reasonable interest adjustment mechanism to coordinate the interests of all parties are helpful to build a stable and efficient cooperation alliance and improve the economic feasibility of marine plastic waste management cooperation. This paper not only provides theoretical support for the global cooperation of marine plastic waste management, but also proves the feasibility of practice and points out the direction for its practice.

1. Introduction

The continued growth in resource use is causing extensive environmental damage, with marine plastic waste pollution being a prominent example. Globally, humanity produces 300 million tons of plastic waste each year, of which, about 11 million tons of plastic waste

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enters the oceans, threatening marine species and ecosystems, impacting human activities and health, and causing at least $13 billion in losses to marine ecosystems every year [1,2]. Without management, plastic waste leaking into the ocean will triple by 2040 and the weight of plastic waste in the ocean will exceed all fish by 2050 [2–4]. Marine plastic pollution has become a global problem to be solved as well as biodiversity loss and climate warming. Significant characteristics of ecosystem relevance, sea water mobility, ambiguity of governance boundary and complexity of governance require global cooperation in marine plastic waste governance. All parties need to actively take action to treat marine plastic waste. At present, more than 60 countries have already set governance targets and introduced relevant legislation [5]. The G20 Osaka Summit in 2019 adopts the "Blue Ocean Vision" initiative to achieve "zero emissions" of marine plastic waste by 2050. The United Nations Environment Programme (UNEP) has launched the "Clean Seas" campaign to find solutions to reduce marine waste, and 63 countries have signed up to it [6]. The Ellen MacArthur Foundation (EMF), in partnership with UNEP, has established the "New Plastics Economy" global commitment to promote the development of circular economy in plastics, with 400 signatories [7]. The World Wide Fund for Nature (WWF) has also proposed the "Net Plastic Nature 2030" initiative, which aims to reduce plastic pollution by improving the global governance framework and accelerating the transition to a circular economy [8]. These actions lay the foundation and provide an example for cooperation on marine plastic waste. Overall, cooperation in the management of marine plastic waste is both necessary and feasible.

Research findings on marine plastic waste governance are distributed at both macro and micro levels. The former focuses on the study of cooperative governance mechanisms [9,10], while the latter on the exploration of reasonable governance measures [11]. The two levels of research are complementary and mutually reinforcing. Specific governance measures lay the foundation for the construction of cooperative governance mechanisms and point the way to practice, while a sound cooperative governance mechanism facilitates the effectiveness of governance measures.

At the macro level, a consensus on international cooperation in marine plastic waste management is gradually forming. Meanwhile, the three-dimensional governance system of global leadership, regional coordination and national implementation has basically taken shape, but overall it lacks effectiveness and needs further improvement [9]. Marine plastic waste governance at the global level takes three main forms: International legislation ("Basel Convention"), "soft law" (resolutions, initiatives, etc.), and voluntary commitments [10], with soft law predominating and lacking a strong binding effect overall. Regional coordination of marine plastic waste is dominated by regional intergovernmental organizations, represented by the European Union (EU) and ASEAN [12], and carried out through multilateral or bilateral cooperation agreements [9]. However, it is faced with a lack of cooperation networks, insufficient governance funds, low institutionalization and unfavorable leading coordination. The government, through legislation and policy guidance, on the one hand, encourages enterprises to accelerate technological innovation and assume social responsibility, and on the other hand, mobilizes the public to raise awareness of environmental protection and participate in "beach clean-up" activities [9].

At the micro level, traditional methods of plastic waste disposal include incineration, landfill and recycling [13–15]. Incineration can seriously pollute the atmosphere and damage human and biological health, and landfills can cause extensive land occupation and serious soil contamination, both of which are environmentally inefficient and not effective in the long term [16]. Recycling has a dual role. On the one hand, it can reduce fossil energy consumption and save resources. On the other hand, differences in technology and management levels between countries can lead to regional environmental impacts and health risks during the recycling process [17,18]. The international trade in plastic waste, as a special case of plastic recycling, fully demonstrates the double impact of recycling. International trade allows plastic waste to flow from one country to another, particularly from developed countries (the main exporters) to developing countries (the main importers), allowing plastics to move around the world [17]. On the one hand, it satisfies the demand for raw plastic in industrial production and reduces greenhouse gas emissions [13], but on the other hand, it contributes to regional environmental impacts and increases the possibility of plastics flowing into the ocean, defeating the original purpose of plastic waste disposal [14].

With the development of the economy, the consumption concept gradually shifts from a traditional linear economy to a circular economy. Building a closed loop to maximize profits and reduce costs in the life cycle has received increasing attention [19,20]. Scholars generally believe that plastic waste management needs to focus on the whole life cycle of plastic [21,22], advocating a reduction in the potential amount of plastic waste entering the sea by taking measures in all parts of the plastic supply chain [23]. Source reduction, circulation control and recycling are the main approaches to marine plastic waste management, corresponding to the main links in the supply chain. In terms of source reduction, on the one hand, developing new biodegradable plastics or replacing traditional plastics with other environmentally friendly materials, on the other hand, using advanced technology to monitor at source, increasing legal and regulatory provisions, and educating consumers to change their behaviors in use. In addition, the UNEP has established a "polluter pay system" through taxation and other means to reduce plastic waste from the source into the ocean [24]. In terms of circulation control, Borrelle [21] advocates a global fund for cross-border waste management and a measurable international agreement on plastic pollution. In terms of recycling, Indonesia has adopted an innovative program of "plastic banks" [25], which converts collected plastic waste into cash and commodities in plastic banks and then processes it into plastic raw materials and delivers them to partner companies to make new products. This business model connects the value chain of plastic waste management and monetizes marine plastic waste, undertaking the dual mission of protecting the environment and generating income for low-income people in the poorest areas of the world [26]. Another similar plan is the "deposit-refund plan". The plan allocates monetary value to waste and creates a market for it, which not only promotes recycling but also encourages people to pick up waste [26]. Canada and the EU have implemented extended producer responsibility (EPR) measures and proved the effectiveness of this method in a country or region [27]. EPR transfers the responsibility of recycling to plastic product manufacturers, and requires them to improve the recyclability of plastics in product design in order to facilitate subsequent disposal [28,29].

Marine plastic waste management cooperation requires investment in economic costs and can bring higher economic value. Some marine plastic waste can be converted into petroleum products to meet energy needs through sorting, smelting and other related technologies. In addition, marine plastic waste management is a public good with significant economic spillover effects. Not only does it reduce the likelihood of accidents at sea and lower shipping costs, but it can also increase the economic output of marine industries and help maintain the stability of a country's marine economy [9,25,30]. Therefore, cooperation in marine plastic waste management is a public good with economic attributes. Countries weigh the economic benefits of marine plastic waste management against the costs of marine pollution and management to decide whether to choose government cooperation.

Some scholars have studied the specific impact of economic factors on plastic waste management. Taking the Rhine River as an example, Li [31] studied international environmental governance cooperation from the perspective of cooperative game, and found that economic strength and domestic benefits brought by governance actions are the main factors affecting the success of cooperation. He also points out that the increase in the number of participating countries is conducive to a shift in cooperation towards a Pareto optimum. Abbott et al. [23] studied potential policies to reduce marine plastic waste pollution from an economic perspective and found that national investment contributed to reducing the pollution and that addressing the problem required a comprehensive life cycle perspective. Willis et al. [32] took Australia as an example to assess the effectiveness of waste abatement campaigns and government policies in reducing plastic waste flows into the oceans. The findings show that the level of the government's investment budget plays an important role in reducing plastic waste pollution, and point out that targeting investment to the most effective strategy will be the key to the success of plastic waste pollution control.

In addition to the economic strength of the country and the benefits of the governance process, a variety of factors such as the level of technology and the amount of tasks involved in governance can influence the strategic choices of the country by affecting the benefits and thus the success of the cooperation [31]. However, the main reason why cooperation on marine plastic waste is difficult to achieve is the conflict in the distribution of interests triggered by the heterogeneity of the economy and society and imbalance in the distribution of the waste [33]. The alliance of marine plastic waste management cooperation is actually a cooperative network composed of cooperative relations and nations [34]. The benefits within the alliance can be transferred through cooperative relations to realize the reasonable distribution of the benefits, which properly handles the interests between countries within the alliance and maintains the stability of it. Therefore, studying the rational distribution of benefits within the cooperation network is of great significance to promote the construction of the network and maintain the stability of the cooperation alliance.

Overall, marine plastic waste management is a public good with economic attributes, and cooperation in management is both necessary and practicable. At present, the consensus on international cooperation in management is also gradually formed, and the measures of governance are abundant, but the feasibility of cooperative governance has not yet been proved. From the perspective of economics, this paper uses the amount of capital investment, technology level of governance and the amount of plastic waste to be treated as the main influencing factors for economic benefits to build a cooperative network game model for marine plastic waste management and demonstrate the economic feasibility of cooperation in marine plastic waste management, in the hope of laying a theoretical foundation and indicating the direction for marine plastic waste management.

Specifically, this paper is organized as follows. The background and literature review are provided in this section. The construction of the cooperative network game model for marine plastic waste management is provided in Section 2. The numerical analysis of the model is provided in Section 3. Finally, discussion and conclusions are respectively provided in Section 4 and Section 5.

2. Cooperative network game model for marine plastic waste management

A marine plastic waste management cooperation alliance is actually a kind of relationship network based on cooperation agreements. The formation of cooperation relationships and the effectiveness of government cooperation are affected by economic, political, social and psychological factors [35,36]. In terms of global governance, the cooperation on marine plastic litter governance is a three-dimensional governance system with global leadership, regional coordination and national implementation [9]. Cooperation on marine plastic litter governance at the regional level is the key to global governance research [10]. Regional-level marine plastic litter governance is led by regional intergovernmental organizations, and represented by the EU and ASEAN [16]. The governance of marine plastic litter in Southeast Asia is characterized by obvious national subjectivity, external participation and a lack of cooperative networks, and faces the practical dilemmas of low institutionalization, insufficient funding for governance and weak coordination of leadership, reflecting current trends in marine governance [37]. In terms of the level of pollution and the focus of treatment, the region has become a priority for future treatment in the wake of the massive influx of plastic waste into the Southeast Asian region following China's solid waste import ban [18,38]. In terms of the realistic basis as well as the future direction, the leaders of ASEAN members signed the "Bangkok Declaration" and the "ASEAN Framework for Action against Marine Management" in 2019, vowing to work together to take holistic measures from land to sea and to accelerate the development of national laws and regulations to combat marine plastic waste. In addition, ASEAN also actively exchanges and cooperates with neighboring countries under the framework of the East Asia Summit and "ASEAN 10 + 3" to jointly explore countermeasures for marine plastic waste management [10]. Expanding the scale of cooperation on the basis of internal cooperation within ASEAN is a priority to solve the problem of marine plastic waste management in this region. Therefore, the article uses the example of ASEAN to illustrate the characteristics of a cooperative network for marine plastic waste management.

The expansion of the regional cooperation alliance needs to meet two prerequisites: [1] the voluntary membership by countries outside the alliance; [2] the consent of the countries in the existing alliance. The key to meeting mutual consent is that the construction of cooperation can bring an increase in economic benefits to both sides. A country joining the alliance means that the country has to build connections with countries in the entire alliance to share both costs and profits. So the number of countries in the alliance and the connection between nodes, that is, the network structure, will affect the distribution of benefits. Considering that country membership requires the consent of all countries in the coalition, we introduced a fully connected network diagram to analyze the specific connections of nodes and study the distribution of benefits. In order to facilitate the observation of connections between nodes, we take ASEAN as an example and propose a collaboration network with 10 nodes as shown in Fig. 1.

Fig. 1 shows the cooperative network diagram of marine plastic waste management composed of 10 national nodes. In the diagram, there are 10 countries, where the red nodes represent nodes of the existing network, the blue nodes represent new country joining, and the countries within the alliance are fully connected (each node has 9 connections). The alliance benefits consist of the benefits of all countries within the alliance, and the benefits can be transferred along the linkages (relationships) between nodes [39], so the structure of the cooperative network affects the distribution of benefits within the alliance.

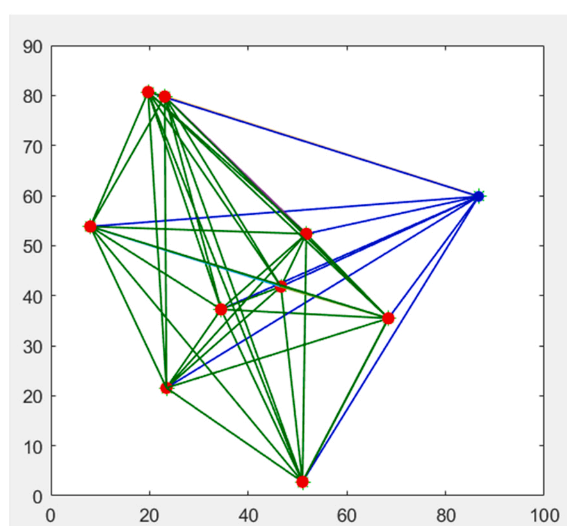

Fig. 1. Cooperative network diagram for marine plastic waste management with 10 nodes. 1) Nodes represent countries in a cooperative network. 2) connections between nodes represent cooperative relationships between countries.

The concept of alliance in traditional cooperative game theory emphasizes the formation of alliances between players in the game, but does not delve into the issue of equitable distribution of utility. Therefore, the traditional cooperative game is not applicable to the cooperative game of marine plastic litter management, while the cooperative network game is more suitable for our study. Network games are new game models based on the connected behavior between subjects under a relationship network [40]. Players in the network game establish connections through cooperative relationships to form a network, and the distribution mechanism is also affected by the network structure and its connection behavior. In the allocation mechanism of cooperative network game, Myerson first considered the network structure, and proposed a new allocation mechanism based on network structure, namely "Myerson value", which takes into account the relationship and connection structure between countries, and is suitable for the benefit distribution problem in the cooperative network alliance [41]. Therefore, this paper designs a cooperative network game model for plastic waste management with the amount of capital investment, the technology level of governance and the amount of marine plastic waste to be treated as influencing factors, calculates "Myerson values" for the distribution of benefits and analyzes the equilibrium of cooperation.

2.1. Model assumptions

Hypothesis 1. Cooperation in marine plastic waste management takes place between countries, all of which are rational economic agents. In the process of game, countries are more concerned with their interests than group's interests.

Hypothesis 2. Countries choose between "cooperative governance" and "separate governance" strategies and the choice is independent between countries.

Hypothesis 3. Cooperation in marine plastic waste management is bound by agreements, and the benefits are transferred between different countries within the alliance through cooperative relationships. The heterogeneity in the level of economic development and the governance technology leads to differences in the benefits. The party with less gains will be compensated through long-term cooperation, while the party with more gains will cede the benefits, in order to maintain a reasonable distribution of benefits and stability within the alliance.

Hypothesis 4. Before joining the alliance, the country used its management technology to treat plastic waste in its waters. When cooperation is reached, the countries in the alliance will share the responsibility of combating marine plastic waste pollution in the alliance through the sharing of technology and experience. That is the level of management in each country will be in line with the highest level in the alliance, and plastic waste pollution will be dealt with by all countries in the alliance [42].

Hypothesis 5. Marine plastic waste management cooperation can bring benefits, which are composed of two parts: Income and costs. A country's capital investment in government cooperation (m), the technology level of governance (A), and the amount of marine plastic waste to be treated (g) all influence the economic benefits gained and the effectiveness of governance [31,32].

We respectively set the income of marine plastic waste management as$U(m,g)$, the cost of management as $C(A,g)$ and the net income of management as V in US dollars ($V = U(m,g) - C(A,g)$). The income and costs of country i in the management of marine plastic waste are shown in Eq. (1) and Eq. (2) respectively.

$$U_i\left(m_i, g_i\right) = -\frac{{g_i}^2}{m_i} + ag_i \ (a > 0) \tag{1}$$

$$C_i\left(A_i, g_i\right) = \frac{b}{A_i}g_i (b > 0) \tag{2}$$

The management of marine plastic waste has economic attributes and the process can be both profitable and costly. The country will gain from the management process, such as the salvaged plastic waste can be refined or made into recycled products to save raw materials, marine ecological restoration and healthy development of marine industries. Income is closely related to the amount of plastic waste to be treated and the level of government investment. With the current high level of plastic waste pollution, a relatively small amount of marine plastic waste removal can bring large benefits. However, as the volume of plastic waste increases, the marginal return per unit of plastic waste treated decreases. When the existing pollution is largely resolved, the benefits of continuing to increase the volume of plastic waste disposal may be lower, or even lower than the costs incurred, resulting in a net negative return. The above characteristics are consistent with the characteristics of a binary primary function with a downward opening. Therefore, we assume an “inverted U-shaped” relationship between the amount of plastic waste disposed of and revenue. In addition, marine plastic waste management is a public product and will not be solved overnight, so governments need to provide long-term financial support to combat the issue. The economic strength of the country is different, the financial support that it can provide is also different. Then the efficiency and quality of governance are also completely different, and the benefits that countries get from it are naturally different. The more government capital invested by the state, the more benefits it receives from it, and the more effective it is at governing [32]. The relationship between the amount of plastic waste to be treated, capital investment and revenue is specified in Eq. (1).

Marine plastic waste management requires cost, which is closely related to the amount of marine plastic waste to be treated and the level of treatment technology. The higher the amount of marine plastic waste to be treated, the higher the cost of management. That is, the amount of marine plastic waste varies in the same direction as the cost of management. In addition, improvements in technology can help to improve efficiency and reduce costs. For example, accurate monitoring data improves the efficiency of management and mechanization of salvage reduces labor costs. Therefore, there is an inverse relationship between the technological level of management and the cost of marine plastic waste management. Eq. (2) is used to reflect the relationship between the above variables and costs.

According to Hypotheses 4 and 5, we use $V(i)$ and $V'(i)$ to denote the benefits of country i when it is not in the coalition and the benefits of joining the coalition respectively, which can be expressed in Eq. (3) and Eq. (4). The benefits of the alliance are expressed in Eq. (5).

$$V(i) = -\frac{{g_i}^2}{m_i} + ag_i - \frac{b}{A_i}g_i \tag{3}$$

$$V'(i) = -\frac{G^2}{m_i} + aG - \frac{b}{A_{\max}^{s\cup\{i\}}}G\left(a > 0, b > 0, A_{\max}^{s\cup\{i\}} = \max_{i\in S\cup\{i\}}\{A_i\}, G = \sum_{i\in S\cup\{i\}} g_i\right) \tag{4}$$

$$V_S = -\frac{{G_S}^2}{M_S} + aG_S - \frac{b}{A_{\max}^S}G_S\left(a > 0, b > 0, A_{\max}^S = \max_{i\in S}\{A_i\}, G_S = \sum_{i\in S} g_i, M_S = \sum_{i\in S} \mathrm{m}_i\right) \tag{5}$$

Where $A_{\max}^{s\cup\{i\}} = \max_{i\in S\cup\{i\}}\{A_i\}$ denotes the level of governance of each country within the coalition $S\cup\{i\}$ is uniformly consistent with the country with the highest level of governance. $G = \sum_{i \in S\cup\{i\}} g_i$ denotes the amount of plastic waste in the waters of the coalition. $M_S = \sum_{i\in S} m_i$ indicates the capital investment within the cooperative alliance *S*.

Hypothesis 6. The achievement of regional cooperation governance will enable technology sharing and enhance the economic utility within the alliance. In addition, the cost of plastic waste management in a country will rise as regional plastic waste pollution requires shared management by the countries involved in the cooperation. Therefore, the economic income and governance costs of countries within the alliance will change after the alliance is reached. For any country *i* and *j*, $I_i$denotes the increase in economic utility of country *i* from shared governance technology after reaching an alliance, and P_i denotes the increase in governance costs of country *i* from increased governance volume after reaching an alliance. Since cooperation is bidirectional, I_j and P_j exist simultaneously. Let $\Delta d_i = I_i - P_i, \Delta d_j = I_j - P_j$, and only when Eq. (6) is established, each participating country will have the motivation to participate in the governance cooperation alliance, which is also a prerequisite for the cooperative game of marine plastic waste governance.

$$\begin{cases} I_i - P_i > 0 \\ I_j - P_j > 0 \end{cases} \tag{6}$$

For utility transferable game $\Gamma = \{N, (S_i), (S_j)\}$, there exists a fixed value Δd such that the utility of the alliance after country *i* joins is shown in Eq. (7):

$$V\left(g|_{S\cup\{i\}}\right) = V\left(g|_S\right) + V'(i) + \sum_{j\in S}\Delta d_j \tag{7}$$

Among them, $\sum_{j\in S}\Delta d_j$ is the benefit that country *i* brings to other countries in the alliance after joining the alliance *S*.

For ease of reading, the variables involved in the model are collated in the tables in the Appendix.

2.2. Myerson value

Myerson extends the "Shapley value" and proposes the "Myerson value", which was then continuously applied and promoted by Jackson and Wolinsky in network gaming. The "Myerson value" is an allocation rule based on the marginal contribution of the participant to the network, and the distribution rule of it is shown in Eq. (8) (in Appendix).

The "Myerson value" has a similar structure to the "Shapley value". The latter allocates based on alliances without regard to the structure of the alliance, whereas the former takes into account the connectivity of nodes under the network structure and makes a fairer and more reasonable profit allocation based on connectivity. Where *S* denotes the number of participants in the network and the change in the amount of value added by node *i* to the network$g|_S$is $V(g|_{S\cup\{i\}}) - V(g|_S)$. According to the above allocation rules, the utility gained by country *i* in the cooperative network game of marine plastic waste management can be expressed by Eq. (9) (Appendix Section 2).

When country *i* chooses a cooperative governance strategy, it not only retains the benefits of individual governance, but also obtains the additional benefits brought by cooperation. Therefore, the benefits of country *i* joining the alliance ($V'(i)$) and the benefits of not joining it ($V(i)$) can be respectively expressed in Eq. (10) and Eq. (11) (Appendix Section 2), and the benefits changes before and after joining the alliance (Δd_i,Δd_j) can be expressed in Eq. (12) and Eq. (12) (Appendix Section 2).

From an economic perspective, the condition for the establishment of the alliance ($S\cup\{i\}$) is that country *i* gains more from joining the alliance than from individual governance, which is $Y_i^{MV}(g, v) \geq V(i)$. In addition, the more the country gains after joining the alliance, the less likely the players to change their strategy, and the more stable the alliance. Taking equations (Eqs. (9)–(12)) into the equilibrium condition and sorting it out, the result is shown in Eq. (15) and Eq. (16) (The specific handling process is described in the Appendix Section 1).

$$C_n^s\left(\Delta d_i + \sum_{j\in S}\Delta d_j\right) \geq 0 \tag{15}$$

$$C_n^s\left(\left(-\frac{G_S(2G-G_S)}{m_i} + aG_S + \frac{b}{A_i}g_i - \frac{b}{A_{\max}^{s\cup\{i\}}}G + s\left(-\frac{g_i(2G-g_i)}{m_j} + ag_i - \frac{b}{A_{\max}^{s\cup\{i\}}}G + \frac{b}{A_{\max}^{s}}G_S\right)\right)\right) \geq 0 \tag{16}$$

Where $G_S = \sum_{j\in S} g_j$ denotes the amount of marine plastic waste within the alliance (S). $G = \sum_{j\in S\cup\{i\}} g_j$ denotes the amount of marine plastic waste within the alliance ($S\cup\{i\}$).

Observing Eq. (15) and (16) we can find that: First, Eq. (15) holds if the condition of $\Delta d_i, \Delta d_j > 0$ is satisfied. That is, cooperation in marine plastic waste management is economically feasible in theory if the preconditions of the cooperative management game for marine plastic waste are met (Eq. (6)).

Second, factors such as the amount of capital investment, the technology level of governance, the amount of marine plastic waste to be treated, and the size of the alliance *S* all influence the country's choice and the stability of the alliance.

1) The amount of capital investment contributes to the stability of the alliance. The greater the amount of capital invested, the more stable the alliance.
2) The technology level of governance directly influences the country's strategic choices and the construction of alliances. The smaller A_i and $A_{\max}^s$, the easier Eq. (16) is to be established, and the more stable the alliance, but the opposite is true for. This indicates that the high level of technology prior to the formation of the alliance is not conducive to cooperation.
3) The amount of marine plastic waste to be treated in the alliance ($S\cup\{i\}$) is negatively correlated with the stability of the alliance. The larger the amount of plastic waste to be treated in the alliance ($S\cup\{i\}$), the less likely it is that a stable cooperative alliance will be formed.
4) As for the size of the alliance, the analysis of the equilibrium results shows that too small an alliance is not conducive to its stability. With the expansion of alliance scale, the possibility of cooperative alliance construction gradually increases, but it is uncertain the effect of an oversized alliance and what size is most appropriate.

2.3. Stability analysis of profit distribution based on "Myerson value"

Exploring the stability of the cooperative network game based on the profit distribution rule of "Myerson value" is to judge whether there is a core solution, that is, whether the solution is within the core of the cooperative network game [39,42,43].

If a game (N, V) is a convex game, then the sub-network will not be separated from the complete network of "Myerson value" distribution. Therefore, the core of this game is not empty and the profit distribution of "Myerson value" $(g, Y^{MV}(g))$ is within the core of the game (N, V) [44]. According to the definition of convex game, if any subset S' and S'' ($S'\subset S'$) in set N and any node *i* satisfies Eq. (17) (Appendix Section 2), then the game is called a convex game. Theorem 1 gives a sufficient condition for the core of a network game to be non-empty.

Theorem 1. In the networkG_H, if the nodes in the network satisfy $\Delta d_i = I_i - P_i \geq 0and\Delta d_j = I_j - P_j \geq 0$(Eq. (6)), the core of the network game is not empty and the profit is distributed within the core of the network.

It has been shown that if the preconditions of the cooperative game of marine plastic waste management are met, the cooperative network game is convex, the distribution of benefits within the core and the "Myerson value" of the cooperative network game model of marine plastic waste management is stable, that is the cooperative governance game coalition is stable (see the Appendix for the prove process).

3. Numerical analysis

Taking into account various factors such as pollution sources, heavy pollution areas, governance focus and the basis of cooperation, the paper chooses three representative countries: China, Indonesia, and Malaysia as participants in the cooperative network game model, calculates the "Myerson value" for profit distribution, and proves the practical feasibility of plastic waste management cooperation. In terms of sources of pollution, while most plastic production is in developed countries, marine plastic waste pollution is mostly from developing countries [26]. China and ASEAN members are believed to contribute more than half of the marine waste in the global oceans [45]. Among them, China was once the world's largest importer of plastic waste and is also a major player in regional environmental governance [38]. In terms of heavily polluted areas and the focus of treatment, great changes have taken place in the world trade network of plastic waste after China's import ban on solid waste. Southeast Asia has replaced China as a new major import region, especially Malaysia and Indonesia. However, the level of economic development and governance technology in this region are still relatively low. Therefore, this region will be a priority for governance in the future [46]. In the light of the practical basis for cooperation, China, Indonesia, and Malaysia are geographically adjacent, and have many areas of cooperation, which have the basis for cooperation in the management of marine plastic pollution. Therefore, we choose these three countries as the players of the game to study the benefits distribution in cooperation management for marine plastic waste and to verify the stability of the distribution of benefits.

3.1. Data setting

3.1.1. Technology level

Among the three countries of China, Indonesia and Malaysia, China is a leader in the management of marine plastic waste [37]. The technology level of marine plastic waste management in China is relatively high, and the cost of management is relatively low, while the technology level of Malaysia and Indonesia is relatively low and relatively close. Therefore, suppose the unit value of management technology for marine plastic waste in China is 2 [42], and for the sake of simplicity of calculation, both Indonesia and Malaysia are set to 1.

3.1.2. Capital investment

We choose the "inclusive wealth index" to reflect a country's capital investment capacity. The higher the inclusive wealth index, the richer the country, the stronger its sustainable development ability, which indirectly indicates that the country has a higher ability to provide financial support for the management of marine plastic waste. Most studies use GDP to measure a country's level of economic development, but GDP does not fully reflect ecological and environmental depletion, making it difficult to judge the sustainability of the economy, while inclusive wealth overcomes this shortcoming. Inclusive wealth, which includes human capital, productive capital as well as natural capital, reflects both a country's affluence and its capacity for sustainable development [47]. According to the "World Inclusive Wealth Report in 2018", the inclusive wealth indexes of China, Indonesia and Malaysia are calculated respectively, and the results are shown in Table 1.

Table 1
Inclusive Wealth Index for China, Indonesia and Malaysia.

Capital ($100 million)\Country		China	Indonesia	Malaysia
Human capital		343,710	38,510	3810
Productive capital		180,000	13,430	6380
Natural capital	Non-renewable Resources	27,620	9450	1720
	Agricultural Resource	40,390	4240	370
	Forest resources	9660	10,670	2090
	Fishery resources	1145	656	428
	Petroleum resources	26,442	7289	1719
	Mineral resources	1181	161	2
	Summary	106,438	32,466	6329
Inclusive wealth		630,148	84,406	16,519

3.1.3. The amount of marine plastic management to be treated

At present, the calculation of marine plastic waste is not accurate, which needs further study [13,48]. We take the amount of plastic waste discharged into the ocean by countries in 2019 as the amount of marine plastic waste to be treated from the perspective of marine plastic waste flows only. The amount of plastic waste entering the sea of these three countries is shown in Table 2.

The amount of marine plastic waste to be treated in China, Indonesia and Malaysia is approximately 0.70707, 0.56333 and 0.73098 (Unit: 100 million kg).

3.1.4. Other variables

Assuming $a = 30$, $b = 1$, where *a and b are coefficients in* Eq. (1) *and* Eq. (2).

3.2. Governance benefits

There are seven options for management between China, Indonesia and Malaysia. For the convenience of writing, we use the three numbers "*1*, *2*, *3*" to respectively represent the three countries of China, Indonesia and Malaysia. Therefore, these seven plans are: {*1*}、{*2*}、{*3*}、{*1,2*}、{*1,3*}、{*2,3*}、{*1,2,3*}. These seven plans can be briefly divided into three scenarios: Governance alone, cooperative governance between two countries, and cooperative governance between three countries, as shown in Fig. 2.

The set data was substituted into the benefit equations (Eq. (3) and Eq. (5)) to calculate the benefits of governance under different scenarios and the results are shown below.

(1) The benefit of {*1*}: $V_1 = 20.859$.
(2) The benefit of {2}: $V_2 = 16.337$.
(3) The benefit of {3}: V3 = 21.198.
(4) The benefit of {1, 2}: V12 = 37.447.
(5) The benefit of {1, 3}: V13 = 42.422.
(6) The benefit of {2, 3}: V23 = 37.535.
(7) The benefit of {1, 2, 3}: V123 = 59.041.

3.3. Profit distribution based on "Myerson value"

According to the Eq. (8), calculating the income Y_i of countries in different alliances, and further calculating the total income obtained by countries in different cooperation scenarios: $\xi 1$, $\xi 2$, $\xi 3$. The symbol of "-"

Table 2
The amount of plastic waste entering the sea from China, Indonesia and Malaysia.

Country	China	Indonesia	Malaysia
Amount (100 million kg)	0.70707	0.56333	0.73098

Data sources: https://ourworldindata.org/. In order to show the influence of the amount of plastic waste to be treated in the calculation results, we have chosen a smaller unit "kg" instead of the tonnes commonly used in this field.

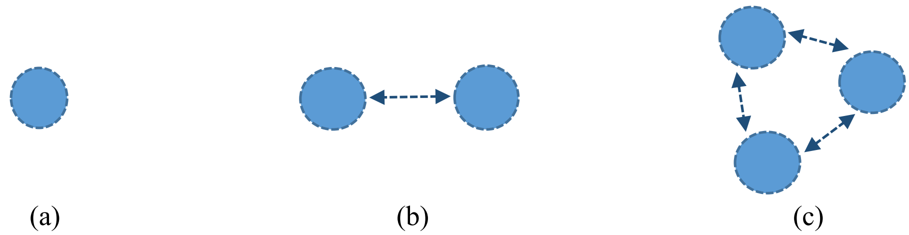

Fig. 2. The classification chart of marine plastic waste management. The circle indicates a country, and the two-way arrow indicates a cooperative relationship between the two countries in the management of marine plastic waste.

in tables below (Tables 3–5) indicates that two countries have formed an alliance and the arrow indicate that the new country wishes to join an existing alliance, as in *2–3←1*. It is worth pointing out that the scenario of "*0←i*" indicate that the country *i* is willing to cooperate in governance, but the other two countries do not have this intention, which is different from the scenario of {*1*} above (in Section 3.2) in which the country *i* chooses individual governance strategy directly without considering cooperation. Therefore, we can interpret this total benefit as the expected benefit of country *i* choosing cooperative governance.

3.3.1. China's gains in different cooperation scenarios

China's total benefits from different cooperation scenarios: $\xi 1 = 6.953 + 3.523 + 3.537 + 7.169 = 21.182$.

3.3.2. Indonesia's gains in different cooperation scenarios

Indonesia's total benefits from different cooperation scenarios: $\xi 2 = 5.446 + 2.770 + 2.723 + 5.540 = 16.479$.

3.3.3. Malaysia's gains in different cooperation scenarios

Malaysia's total benefits from different cooperation scenarios: $\xi 3 = 7.006 + 3.594 + 3.533 + 7.188 = 21.381$.

The total distribution gains from different cooperation scenarios obtained by China, Malaysia, and Indonesia are respectively greater than the gains of their separate governance ($\xi 1 > V1, \xi 2 > V2, \xi 3 > V3$). Therefore, if China, Indonesia, and Malaysia cooperate in the field of marine plastic waste pollution management, the benefits of cooperation management will be greater than the benefits of individual governance. In other words, the alliance of these three countries can obtain higher economic benefits by improving governance efficiency and help solve the regional marine plastic pollution problem.

3.4. Stability analysis of profit distribution

Integrating the benefits of Sections 3.2 and 3.3 to get Table 6. According to the data in Table 6 to test whether the profit distribution is at the core of the game.

Test whether the profit distribution plan based on "Myerson value" is at the core of the game.

$$Y_1^{MV}(g,v) + Y_2^{MV}(g,v) = 21.182 + 16.479 = 37.661 > V\left(g|_{\{1,2\}}\right) = 37.477$$

Table 3
China's gains in different cooperation scenarios.

	Alliance *S*	*0←1*	*2←1*	*3←1*	*2–3←1*
1	$v(g\|_{s\cup i})$	20.859	37.477	42.422	59.041
	$v(g\|_s)$	0.00	16.337	21.198	37.535
	Δv	20.859	21.140	21.224	21.506
	$\|s\|$	0	1	1	2
	$w(\|s\|)$	1/3	1/6	1/6	1/3
	Y_i	6.953	3.523	3.537	7.169

Table 4
Indonesia's gains in different cooperation scenarios.

	Alliance *S*	*0←2*	*1←2*	*3←2*	*1–3←2*
2	$v(g\|_{s\cup i})$	16.337	37.447	37.535	59.041
	$v(g\|_s)$	0.00	20.859	21.198	42.422
	Δv	16.337	16.618	16.337	16.619
	$\|s\|$	0	1	1	2
	$w(\|s\|)$	1/3	1/6	1/6	1/3
	Y_i	5.446	2.770	2.723	5.540

Table 5
Malaysia's gains in different cooperation scenarios.

	Alliance *S*	*0←3*	*1←3*	*2←3*	*1–2←3*
3	$v(g\|_{s\cup i})$	21.198	42.422	37.535	59.041
	$v(g\|_s)$	0.00	20.859	16.337	37.477
	Δv	21.198	21.563	21.198	21.564
	$\|s\|$	0	1	1	2
	$w(\|s\|)$	1/3	1/6	1/6	1/3
	Y_i	7.066	3.594	3.533	7.188

Table 6
The benefits of alliances and countries.

Alliance	Benefits of alliances	Benefits of countries			Total benefits of countries
S_{12}	*1–2*	*1*	*2*		
	37.477	21.182	16.479		37.661
S_{13}	*1–3*	*1*	*3*		
	42.422	21.182	21.381		42.563
S_{23}	*2–3*	*2*	*3*		
	37.535	16.479	21.381		37.860
S_{123}	*1–2–3*	*1*	*2*	*3*	
	59.041	21.182	16.479	21.381	59.042

$$Y_1^{MV}(g,v) + Y_3^{MV}(g,v) = 21.182 + 21.381 = 42.563 > V\left(g|_{\{1,3\}}\right) = 42.422$$

$$Y_2^{MV}(g,v) + Y_3^{MV}(g,v) = 16.479 + 21.381 = 37.860 > V\left(g|_{\{2,3\}}\right) = 37.535$$

$$Y_1^{MV}(g,v) + Y_2^{MV}(g,v) + Y_3^{MV}(g,v) = 21.182 + 16.479 + 21.381 = 59.042 > V\left(g|_{\{1,2,3\}}\right) = 59.041$$

The above calculation results show that the profit distribution based on the "Myerson value" is within the core internal of the game. From an economic point of view, China, Indonesia, and Malaysia will choose cooperative governance strategies and their strategic choices are stable.

4. Discussion

From the perspective of sustainable economics, this paper takes the amount of capital investment, the technology level of governance and the amount of marine plastic waste to be treated into consideration, and constructs a cooperative network game model for marine plastic waste management. The results show that the level of technology, the amount of capital invested, the amount of plastic waste and the size of the coalition all influence a country's choice. Some of the results of this paper have similarities and differences with those of Li [31], Willis [32], and Abbott et al. [23].

4.1. Technology level

The level of technology influences cooperation on marine plastic waste management by affecting the cost and efficiency of management. At the level of cost and efficiency, the two factors are the focus of a country's strategic choice. Therefore, the technology level is of great significance to the construction of alliances. As far as marine plastic waste is concerned, the higher technology level can not only reduce the labor cost of salvage, but can also maintain the stability of salvage and improve the efficiency of it [10].

As for the construction of alliance, the achievement of governance cooperation means the sharing of governance tasks, which can make cooperation governance more costly for some countries with high levels of technology. Therefore, when faced with the accession of a country with a lower technology level and a heavy governance task, a coalition with a higher technology level will reject it, considering the significantly higher cost of governance. The same situation will appear in countries with higher technology levels.

Improving the technology level is an important task in the construction of cooperative alliances now. However, the overall technology level of marine plastic waste management needs to be improved. Current technology development is immature and the international community has not yet invented equipment that can efficiently collect and clean up marine plastic waste, relying instead on traditional salvage methods that are time-consuming and inefficient [49]. Therefore, technological innovation and application should be accelerated in the future. First, encourage the invention of technology equipment for collection, cleaning, etc. Second, applying the latest technologies such as blockchain to record, track and save costs to facilitate the recycling of plastics. Third, promoting the establishment of a platform for exchange and cooperation among marine environmental protection social organizations, universities and scientific research institutes to improve the professional ability of marine plastic waste management.

4.2. Capital investment in governance

The equilibrium results indicate that capital investment in governance plays an important role in facilitating the construction of cooperative coalitions for plastic waste governance. The results directly support the view of Willis et al. [32] and Abbott et al. [23] that national investment has a significant impact on plastic waste pollution management. It also indirectly supports the view of Li [31] that economic strength is a major factor influencing the success of pollution control in the Rhine.

Countries with high economic strength have the ability to continuously provide adequate funding, which provides financial support for marine plastic waste management and ensures the effectiveness of plastic waste management. Marine plastic waste management is a public product with economic attributes, and the external characteristics of governance require the government to bear the cost of governance. The seriousness of plastic waste pollution, the difficulty of management, and the complexity of management work place high demands on the countries' ability to provide sustained financial support. Countries with a high level of economic development have the ability to provide sufficient funds to support technological research and development, promote the improvement of governance, and thereby ensure the quality of governance. However, data shows that most plastic in the ocean originates from offshore developing countries, such as Malaysia, China, Indonesia, etc. [23,44]. Most of these countries are facing large or small problems in continuing to provide adequate governance funds, and are more concerned with the economic benefits brought about by governance. Therefore, how to ensure that countries with lower economic levels can provide sufficient financial support in the process of plastic waste management is a key issue.

EPR provides a potential solution. EPR passes the responsibility for recycling to manufacturers of plastic products, requiring them to improve the recyclability of plastics in their product design [26]. Enterprises then transfer some or all of their costs to consumers through the product sale as a result of market mechanisms [23]. The implementation of EPR has enabled the sharing and shifting of the cost of plastic waste management, directly reducing the burden on the government and indirectly raising the environmental awareness of the whole society. However, there is a limit to the level of consumer affordability, and this limit affects the effectiveness of the EPR policy and of marine plastic waste management. Therefore, in the future, it is necessary to set a reasonable proportion of consumers' burden according to their affordability, psychological expectations and the scope and extent of EPR policy implementation, so as to optimize the management effect of marine plastic waste.

4.3. The amount of marine plastic waste to be treated

The amount of plastic waste to be processed affects the formation of alliances by affecting the cost of governance. The more plastic waste to be processed within the alliance, the greater the costs to be borne and the fewer the benefits to be gained, so the less likely it is that a cooperative alliance will be formed. The result is consistent with the view of Li [31] that national gains from government actions are the main factor influencing the success of cooperation.

Marine plastic waste has economic attributes. The management of plastic waste is both profitable and costly. The results of the study show that the amount of plastic waste to be treated within a newly formed cooperative alliance (G) is negatively correlated with the benefits of management, especially when the overall technology level of the new alliance ($A_{\max}^{S\cup\{i\}}$) is low. This suggests that the cost of management has a greater impact than revenue in the construction of cooperation in marine plastic waste management. Therefore, on the one hand, raising the technology level of management to reduce the cost of management is a priority task, and on the other hand, we need to properly allocate the task of management according to the technology level and accurate data on the distribution of plastic waste in each country to address cost-sharing issues.

However, the distribution of plastic waste stocks and potential into the sea is not clear, and the difference in measurement technology between countries has caused information asymmetry in distribution data, which brings challenges to the improvement of marine plastic salvage efficiency and accurate estimation of costs and hinders the formation of cooperative alliances [26]. On the other hand, the heterogeneity of countries in terms of level of development and technology means that the costs of an equivalent amount of plastic waste vary greatly, which hinders the impact of the economic benefits of plastic waste management and affects the distribution of the benefits. Overall, all the above factors pose a challenge to the precise management of plastic waste and the rational allocation of management tasks.

The following measures can be taken to address the above issues. First, countries should encourage technology innovation, improve technology level and share technology (Satellite monitoring technology, salvage technology, processing technology, etc.) in order to achieve accurate prediction of plastic waste distribution and improve the imbalance of technology level in countries. Second, establishing a sound market mechanism to play the function of creating benefits from plastic waste to promote the formation of cooperative alliances. Third, properly handle the demands of various stakeholders, unified interest goals, establish and optimize interest sharing and compensation mechanisms.

4.4. Size of the alliance

The equilibrium results suggest that the size of the alliance has an impact on cooperation in marine plastic management. Too small an alliance is not conducive to cooperative alliance building, which gradually becomes more likely as the size of the alliance increases, but the exact impact of an oversize alliance on cooperation is not clear. Overall, it is not clear what size is most appropriate. Li [31] takes the Rhine River as an example to study international environmental governance cooperation from the perspective of cooperative game. It is found that the increase in the number of participating countries is conducive to the transformation of cooperation towards the Pareto optimal state, which indicates that the bigger the alliance, the better. Li's [31] findings are not in line with those of this paper. The reason may be the selection of the study area and the setting of the number of countries. The scope of the study in this paper is the global sea and the countries involved include all sovereign states (195), whereas the scope of Li's [31] study is the Rhine and the number of countries is limited. If the scope of Li's [31] study is expanded or narrowed down for this paper, it may yield the same findings in size of the alliance for both papers.

The size of the alliance has a dual impact on the formation of the plastic waste management cooperation alliance. On the one hand, a larger alliance can attract more countries to join and exploit the scale effect of plastic waste management. On the other hand, when the size of the alliance increases to a certain limit, the problem of the uneven level of development of the countries within the alliance will become more apparent. Countries with different levels of development also have different interests, which makes coordination within the alliance more difficult and raises the cost of maintaining its stability. The equilibrium results of the model show that the size of the alliance affects the equilibrium, but it is not better to have a larger or smaller alliance. Therefore, setting a reasonable alliance size and coordinating the relationship between income and cost are the key to maintaining the stability of the alliance.

Exerting the influence of countries rationally with higher status within the alliance plays an important role in coordinating the distribution of interests within the alliance and maintaining the stability of it. There are always some countries with relatively strong comprehensive strength, high status, great influence and close relationships with other countries in the alliance. These countries are suitable to assume more responsibilities and obligations in cooperative governance [50]. In addition, in the cooperative network, on the one hand, these countries can give full play to their influence to coordinate the distribution of interests within the alliance; on the other hand, they can play a leading role by virtue of their network status to affect other countries to follow their strategic choices. It is worth noting, however, that major countries can not only maintain the stability of the network with their leading power, but also undermine the stability of the network. Therefore, it is a focus of future research to properly play the positive role of great power influence and leadership.

5. Conclusion

From the perspective of economics, this paper takes the amount of capital investment, the technology level of governance, and the amount of plastic waste to be treated as variables that affect the distribution of cooperation benefits, and constructs a cooperative network game model for marine plastic waste management. The conclusions of the article include : First, a country's choice of strategy is influenced by the technology level of governance, the amount of marine plastic waste to be treated, the amount of capital invested, and the size of the alliance, the first two of which not contribute to the achievement of cooperation and the stability of the alliance, while the amount of capital invested has a facilitative effect. As for the size of the alliance, too small an alliance is not conducive to cooperative alliance building, which gradually becomes more likely as the size of the alliance increases, but it is uncertain the effect of an oversized alliance and what size is most appropriate. Second, marine plastic waste management cooperation is economically feasible both in theory and practice. The profit distribution mechanism based on "Myerson value" also confirms the stability of the cooperative alliance. Third, the economic feasibility of marine plastic waste management can be improved by encouraging the development and application of innovative technologies, adopting EPR measures to reasonably transfer the management cost, and properly exerting the influence of important countries within the alliance to coordinate the distribution of benefits.

Contributions of the paper include: First, providing theoretical support for cooperation of marine plastic waste management. Second, proving the economic feasibility of practice and pointing out the direction for practice. Third, this paper also identifies future research directions for the construction of a collaborative alliance for marine plastic waste: 1) Studying how to set a reasonable proportion of consumers' burden according to their affordability, psychological expectations and the scope and extent of EPR policy implementation, so as to optimize the management effect of marine plastic waste. 2) How to build a mechanism to coordinate interests within the alliance and maintain its stability. 3) How to properly play the positive role of great powers' influence and leading power. More importantly, the design of the model and the selection of specific variables follow the general structure of ecological governance cooperation issues. The model and the areas of application of the findings can therefore be appropriately extended from the existing ones. However, every problem has its own particularities and specific problems have to be analyzed in detail.

There are some limitations in the paper. On the one hand, there are many factors that affect the construction of cooperative alliance for marine plastic waste management, such as politics, society, diplomacy, and the economy. However, this paper only studies the feasibility of cooperation from an economic perspective. On the other hand, the cooperative management game of marine plastic waste between countries is more complicated, and the game model designed in this paper is more ideal, so it cannot fully replicate the actual game process. Therefore, in the future, more influencing factors could be taken into consideration to comprehensively explore the feasibility of marine plastic waste management.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2023.105504.

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