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Review

Indonesia's Renewable Natural Resource Management in the Low-Carbon Transition: A Conundrum in Changing Trajectories

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Abstract: A paradigm shift is required to transform current natural resource management (NRM) in Indonesia's decision to move into low-carbon development to achieve the greenhouse gas emission target. No study has been conducted to assess whether or not the current approaches are reliable in anticipating the conundrum of the new juncture. We reviewed 10 cases of NRM practices in Indonesia from 2019–2023 collected from the Scopus dataset by integrating the prisoner's dilemma approach into the socio-ecological framework to analyze the practices and the anticipated gaps. Our finding revealed that socio-economic governance is the dominant view in interpreting the competition between personal and collective interests in NRM. Seeing NRM as an allocation problem and the excessive use of the legal normative approach in interpreting and addressing the problem are flaws in the approach. Combining the prisoner's dilemma approach with the socio-ecological governance framework enabled us to address the flaws. Promoting polycentric governance that accommodates social trust, reciprocities, and socio-ecological beliefs and reduces uncertainties about ownership and the resources necessary to reduce defective behavior is a solution to transform the structure of the competition. Revising the socio-economic payoff into a socio-ecological value-oriented institution is the strategy to address the conundrum.

Keywords: low-carbon development; natural resource management; prisoner's dilemma; environmental stewardship; low-carbon development; non-utilitarian; reward and punishment; incentive; applied game theory; payoff; Indonesia

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1. Introduction

Effective natural resource management (NRM) policies are essential for achieving sustainable development goals. Indonesia enacted ground-breaking policies in low-carbon development in order to move the nation towards the new development pathways (Presidential Decree No. 98 of 2021 on the Implementation of the Economic Value of Carbon, and Long Term Strategy on Low Carbon and Climate Resilience in 2022). The country's transition to a low-carbon economy advances with the implementation of these policies. A new era of natural resource management in the country are in the making.

Competition between self-interest and collective interest is the classical phenomenon in the natural resource extraction for ecosystem goods and services. Fair and equitable allocation of the resources are the continuous concern among the resources extractors for satisfying the subsistence needs and the supply chains. Since the introduction of the Tragedy of the Commons by Hardin [1], the contestation between self-interest and public benefit has been the main issue in promoting sustainable NRM. In a world where a scarcity of natural resources is the norm, the preference of the landowner to maximize their self-interest by taking a defective strategy and free-riding will hampers efforts to achieve a sustainable landscape and natural resource management [2]. This preferred option makes sense for users, as they can obtain the resources directly. However, this option is suboptimal or the worst choice, as the short-sighted action will result in losses for both the individual and the group. The optimal result obtained by the user of a natural resource in the short-term results in suboptimal benefits or resource depletion in the long term. This paradox

was brought up by Herbert Simon, who termed the situation "bounded rationality" [3]. In the long run, resource depletion will result from individuals' rational decisions to maximize their outcomes based on rational reasoning. This typical allocation issue has never been resolved in high-carbon development trajectories.

The transition to low-carbon development will exacerbate the unresolved allocation problem as resource users are required to provide a fair share to ecosystems from which resources have been extracted. At this new development juncture, individuals and the collective are obligated to return to nature the benefits and services they have received in the past, making sustainable NRM issues a new dilemma. For the purpose of aligning the policies and practices of NRM and determining the appropriate strategy or approaches, a comprehensive overview of this phenomenon is required.

The management of renewable and nonrenewable resources results in a trade-off [4,5]. The commodities produced will provide economic benefits [6] to resource managers and users. In contrast, ecological destruction and emissions from production or extraction processes will have a negative impact on the environment and the collectives [7]. This study focused on examining the crucial issues in NRM that rendered the transition to low-carbon development from the high-carbon development pathway ineffective. This decision is made as the sustainable management of renewables leads to a conflict between the individual and the group, which, in many circumstances, leads to a prisoner's dilemma (PD) [8].

This study aims to assess the perspective or approaches applied in Indonesia in analyzing and interpreting the competing people and ecosystem needs in the management of renewable natural resources that will potentially impede the sustainability of renewables. The Section 2 of this study will examine the potential of the PD approach as an option to address the anticipated gaps and limitations of the existing approaches. We will define a strategy or approach to align NRM policy and practices with a sound perspective and approach by integrating the PD into the socio-ecological governance framework for advancing NRM in the new low-carbon pathway.

This objective is strategic as it may help planners, practitioners, and researchers adjust their approaches and views on NRM issues. We are motivated to present a new framework based on a holistic paradigm to enable the respected actors to find better solutions in this area given the nation's commitment toward low-carbon development pathways.

In the following section, cases from Indonesia are used to illustrate challenges and the potential best practices. The Section 2 of the study examines the application of the PD, an approach in constructing a conflicting situation in game theory, to the socio-ecological governance framework. The following discussion will synthesize the findings to formulate strategi for advancing the sustainability of NRM in the era of low-carbon development. The study will conclude with implications for a new paradigm in promoting resource management taking into account the fundamental motivation of humans as self and collective and the right of the planet to claim the same.

In this review, we try to identify determinants of a PD outcome for strengthening the current planning and decision-making practices in NRM and formulate strategies for optimizing the outcome of a PD-related problem in the sector. We complete this paper by adding a conclusion, adding value to the study, and identifying a further research agenda to address the existing gap in operationalizing the PD and game theory framework in renewable NRM that is relevant for Indonesia and other developing economies.

2. Materials and Methods

This work is a case study of the renewable NRM practices in Indonesia based on the research published in the Scopus dataset from 2019 to 2023 and the PD related studies from the Google Scholar dataset.

For NRM cases in Indonesia, the following procedures were used to select the articles for review. We found 1236 articles using the keywords "natural resource management in Indonesia". We include only English language journal articles (n = 759) and restricted

the study period to 2019–2023 (n = 299). We refined the topic by selecting only articles with the subject areas "environmental science", "social science", and "agriculture and biological science" (n = 244), and then further refined the results using the keywords "Indonesia", "environmental protection", "conservation of natural resources", "natural resources", "sustainability", "conservation", "conservation management", and "ecosystem" (n = 150). Again, we excluded the following irrelevant subject areas: "energy", "earth science", "economics and business management", "engineering", "medicine", "bioc", and "computer." (n = 91) and excluded the keywords "arts", "business", and "veterinary" from the 91 initial articles (n = 88). We excluded a review and a brief survey (n = 81) and "animals" to arrive at n = 69. We excluded articles from the following three journals due to irrelevant content to this study objective: "Journal of Environmental Management", "Hasanuddin Law Review", "Science of the Total Environment", "Aacl Bioflux", "Agronomy", and "Aquaculture" (n = 59). We downloaded the fifty-nine articles. Thirteen of the selected articles could not be downloaded due to broken links, while five were paid articles. We reviewed the titles of the 41 articles and decided not to process 22 of them. After reviewing the abstracts of the 21 articles, we determined that 10 of them met the criteria for this study. This material selection process conformed to the PRISMA minimum standard for literature reviews.

Materials for assessing the PD were retrieved from Google Scholar datasets. Using the following keywords, we identified relevant articles for the review: "prisoner's dilemma in NRM", "game theory in NRM", "cooperation in prisoner's dilemma", and "determinants of prisoner's dilemma in NRM." We used the software Publish or Perish, v. 8.9.4536 to retrieve the articles from Google Scholar, and we only collected 200 papers for each phrase. A total of 800 papers for the four phrases (n = 800) were collected. We included open access only for the analysis and came up with 436 articles. The remainder (n = 364) were excluded due to being paid articles (n = 317) and corrupted articles (n = 47). We examined the retrieved articles by screening the words "renewable NRM" in the title and abstract. We also excluded the following categories: review articles, book chapters, and dissertations. We ultimately reviewed (n = 57) articles for this paper based on these inclusion and exclusion criteria.

We assessed and analyzed the materials by identifying the practices of NRM in the study area, assessing and analyzing the mechanisms applied in observing and interpreting the practices, and reviewing the application of a game theory [9] known as prisoners' dilemmas in renewable NRM and their determinants. The results of the analyses were then synthesized against the socio-ecological governance framework that is relevant to the transition to a low-carbon development pathway. We concluded the analysis by suggesting strategies and approaches for bridging the gap. The framework for this analysis is as follows (Figure 1).

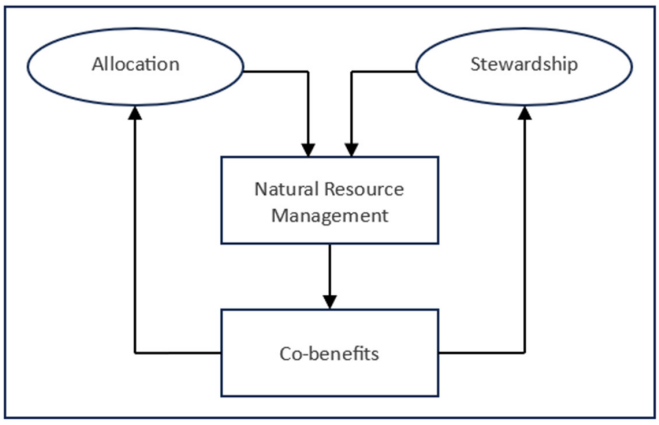

Figure 1. Socio-ecological governance framework.

3. Results

3.1. NRM and Just Transition in Indonesia

The management of natural resources, particularly renewable ones, is a perpetual topic of debate in human society. Indonesia, located on a tropical continent, is endowed by nature with abundant natural resources that provide opportunities for livelihoods and economic growth. The country's commitment to taking a new trajectory toward low-carbon development requires us to reflect on the existing practices for aligning to the new pathways. We reviewed 10 articles (Table 1) for illustrating the current practices (2019–2023).

Table 1. Lists of reviewed articles.

No	Articles	References
1	Traditional ecological knowledge on the slope of Mount Lawu, Indonesia: all about non-rice food security	[10]
2	Law Enforcement and Community Participation in Combating Illegal Logging and Deforestation in Indonesia	[11]
3	Preserving the Sustainability of Natural Resources and Agro-Ecosystems in Tidal Swampland Through Local Wisdom in Indonesia	[12]
4	Policy on Forest Land Use Change for Oil Palm Plantations in Lamandau Regency, Central Kalimantan Province, Indonesia	[13]
5	Polycentric Environmental Governance to Achieving SDG 16: Evidence from Southeast Asia and Eastern Africa	[14]
6	Resource boom and the politics of accountability at the sub-national level: Insight from Indonesia.	[15]
7	Creating commons: Reflections on creating natural resource management regimes in South Sulawesi, Indonesia	[16]
8	Customary forests in West Papua: Contestation of desires or needs?	[17]
9	Developing the assessment and indicators for local institutions in dealing with forest fire dilemmas	[18]
10	The institutional environment of the palm oil value chain and its impact on community development in Kapuas Hulu, Indonesia.	[19]

In Indonesia, oil palm plantation [19], the traditional management of swamp forest for rice paddy farming [12], forest destruction due to fire [12], and customary forests for combating deforestation [11,13,17] are relevant cases of NRM practices that need to be revisited in the new low-carbon development pathway. Competing interests among the subsistence needs of the local communities, the state's interest in economic growth [14,17], and the interests in profit-making entities [13] are the main issues to be addressed in NRM. Local communities manage NRM for their subsistence needs, such as food and trees [17,19], whereas the private sector manages the forest to profit from commodity markets [11,13]. The state is the third actor representing the collective to ensure NRM continues to serve the public and ecological needs [14]. The limitations of the legal normative-oriented institution mechanism to accommodate local interests [14] and the limited capacity of local agencies to empower individuals to obtain recognition of their rights [20] remain obstacles to balancing the competing interests. By establishing the agreed-upon mechanism, local governance was found to be more effective at balancing the competing interests [10,16]. Social forestry is a state-recognized mechanism that is seen as promising [11,13,17] in addressing this complexity.

The combination of collective action [16] and political incentives for local leaders [15] is a potential best practice for promoting collective action among individuals in a group at the community level and policy leaders' commitment to sustainable NRM. This incentive has proven to be an effective tool to keep the commitment of the elite in Bojonegoro Regency [15], but the efficacy of the approach in balancing the interest of the self, collective, and nature in NRM for a low emission and productivity trade-off remains to be determined.

Polycentric environmental governance [14] is the missing element in the country's current approach (based on the scope of this study) that must be strengthened to transform NRM practices into an effective tool for the low-carbon transition. Adopting and adjusting the effective mechanism of the local agrarian communities in striking a balance among the self–collective–nature interests as traditional ecological knowledge [10], such as that held by Lawu Mountain communities, is a potential element of optimizing the social–ecological value that is critical in the low-carbon transition pathway.

Rebuilding shattered trust by establishing a clear consensus regarding contribution and penalties among farmers in Sulawesi's Tompobulu communities has been effective at promoting collective action among resource users [16].

Applied normative empirical approaches in analyzing relationships between the state and communities in combating deforestation and forest degradation [11] highlighted the necessity of enforcing legal structure, legal substance, and legal culture for sustainable forest management. The author acknowledged community empowerment and social forestry; however, it is unclear how the emphasis of the legal-normative approach will be able to balance access and benefits between the public represented by the state and the community.

Promoting elections as a reward and punishment mechanism to encourage local elites to foster accountability in sustainable resource management is another form of governance for individuals and collectives demanding their right to equal resource allocation [15]. This mechanism protects Bojonegoro (a regency in Central Java) from the resource curse, a common occurrence in regions with abundant natural resources.

The belief system practiced by the communities surrounding Lawu Mountain in Central Java is an example of a stewardship-based NRM practice. Local practices that strike a balance between self-interest, collective interest, and ecological interest produce socio-ecological harmony between humans and nature [10]. The cultural practice of uba rampe (offering back to nature as a form of ecological reciprocity) and the cultural belief that inappropriate land use choices (planting rice on the mountain slope) cause disasters are examples of culturally and socially validated stewardship perspectives that promote sustainability.

In contrast to the claims of [10,12,16] clearing tidal one swampland for rice paddy cultivation and incorporating indigenous knowledge into activities is moral from a socio-ecological standpoint, despite ignoring the ecosystem's right to remain intact in order to reduce greenhouse gas emissions.

3.2. Behavioral Approach in NRM

We argue that a game theory-based approach, particularly the PD, has the potential to transform the current allocation-dominated perspectives into a form of environmental stewardship for promoting sustainable NRM. The PDs are a potential framework inder which to address the unresolved allocation problem in renewable NRM [21,22]. Economic institutions that foster trust, reciprocity, and cooperation are the answer to PD as a shared environmental issue [23].

Ref. [24] used the PD model to examine collective action in the South China Sea (SCS) fisheries. He introduced the concept of 'exit' to reflect the dichotomy of choice faced by agents in the 2 × 2 classical PD model. Ref. [24] introduced the move option, which is the strategy of a fisher as an agent in the PD to move to different geographical areas as a response to the decrease in return due to the depletion of fishery stock. The introduction of the exit and move option by [24] is a useful framework under which to adjust the dichotomous strategy that was commonly used in the classical PD framework to accommodate the real motivation of an agent and boundaries.

Ref. [8] conducted an experiment to test the contribution of nonutilitarian consideration to escaping the PD. They introduced a value game rather than a payoff game, which was commonly used in classical PD. The introduction of nonutilitarian value will retain the value of achievement for nonutilitarian actors, but it will diminish the agents who only recognize the utilitarian value. The authors argue that addressing a tension between short-term self-interest and long-term public benefits is not an optimization problem, but a

paradigm shift in relation to nature. The assertion made by [8] is compelling as it recognizes the role of value in determining the agent's decision and preference. However, this approach has never been applied to test the behavior of resource users in the field, making it relevant at a theoretical level.

Ref. [22] used the 2 × 2 game theoretical model to analyze a deforestation issue. This study revealed that the PDs and other forms of social dilemmas, such as the stag hunt dilemma (SHD), emerge due to the influence of both human and environmental factors. The theoretical approach developed in this work is a promising one for integrating the contribution of non-human and non-psychological factors affecting the utility of actors in shaping their actions for optimizing their payoff. The field implementation of the framework is required to showcase the contribution of the factors to the stakeholders' and land users' preferences.

Ref. [21] examined the potential application of the game theoretical model in conservation work. The author examined three conservation issues to show how the game theoretical perspective can be a framework under which to balance competing self-interests and public benefits in common pool resource management. Two advantages of the application of the game theoretical approach in conservation decisions are that it helps discover solutions based on the problem structures, and it is also able to indicate the likely outcome of conservation efforts if a certain game is played by the involved actors or agents. This predictive capacity gives the game theory perspective an advantage in modeling robust and reliable decisions as long as the uncertainty of the theoretical model can be reduced. The game theory perspective can be implemented as a hybrid with decision analysis to transform the preferred game played by the actors into a cooperative action.

Ref. [25] tested the prisoner's dilemma as a framework for addressing the problem of Arctic common pool resources. Realizing the complex competing interests among Arctic actors and sectors, they concluded that access to information was the cause of the collaboration's unexpected outcomes for players. Inequality of access to non-market and non-monetary information is one of the most difficult obstacles to achieving a consensus among actors or players in the management of natural resources.

Ref. [26] conducted an analysis of forestland governance using the game theoretical model in Zagros, Iran. The results indicate that Iranian forest management plays a cooperative game with the local communities to optimize payoffs. They also use economic value (net present value) for measuring community payoffs and forest density as an indicator of forest protection. However, they did not check in advance the appropriateness of the payoff or utility approach to be used as a norm rather than an assumption in the field study. Ref. [27] utilized the prisoner's dilemma game approach to manage the Portuguese national park, which was intended to be a protected area. The author drew the conclusion that the implementation of the co-management model optimized the outcome for the park's stakeholders, utilizing incentive structures that have been shown to motivate stakeholders toward cooperative behavior, thereby optimizing their payoff. Numerous reasons have been identified for the limited adoption of the PD approach in studying land use and NRM decision-making. These include the predominance of the legal normative approach in analyzing competing interests in forest and renewable NRM, the perspective that unsustainable resource management was a result of poverty and a lack of awareness of the actual condition of the resources, the assumption that law enforcement and better governance will change behaviors from dysfunctional to cooperative, and the decision-maker's confidence that the introduction of market-based incentives will transform defective behaviors. The adoption of the PD approach is urgently needed to transform the above legal normative method and perspectives. As shown in the following table (Table 2), several PD game framework determinants have been identified.

Table 2. Determinants, mechanisms, and the proposed solution to increase cooperative behaviour for solving a PD.

Determinants	Mechanism	Proposed Solution
Institutions	Cultivating trust, reciprocity, and collaboration	Reduce transaction costs, encourage investment in collective activities, and facilitate the accomplishment of collective goals
Social Interaction	Neighborhoods, neighbors' strategies, social projection, reciprocity, affected third parties, historical and social comparisons, and dynamic rewiring	Optimizing conditions for maximizing social cooperation and minimizing the 3 other rules (near-there, repetition, and reaction).
Reward and punishment	Individual interest, public behavior, responses to rewards and punishments, and the attitude toward punishments influencing self-regarding preference Punishment increases cooperation	Reference points, catch ratio, confirmation consistency of individual preferences, and no free-riding
Value	Social value orientation (pro-social, pro-self, individualist, and competitor)	SVO, utilitarian, and non-utilitarian value.
Uncertainty	Natural resources uncertainity will increase exraction efficiencies hence accelerating depletion	Inventarization of natural resources and reduced assymetic information about the state of natural resources
Self-psychology	A psychological nudge to frame the environmental issues as a collective concern will increase collaborative behavior	Increasing the incentive above the reference point and introducing a psychological nudge as a policy-making tool.

3.2.1. Institution

The institution is seen as a determinant of cooperative behavior in PD games. Humans prioritize their own self-interest over that of the collective, so setting up an appropriate institution is an option for accounting for externalities. Market-based instruments (MBI) may discourage cooperative behavior, so institutional development should prioritize the creation of institutions that foster trust, reciprocity, and cooperation [23].

The existence of formal and informal rules is another institutional dimension that will facilitate trust. According to [28], impartiality, cohesion, and favorable cooperation terms can all serve as motivations for trust. Trust among the agents or stakeholders participating in collective action may lower transaction costs, incentivize collective efforts, and facilitate the achievement of collective objectives. Mutual trust enables collective benefits that are greater than those obtained by an agent acting individually, and compensates for reduced time and costs by limiting the requirement to oversee the other's behavior and compensating with reciprocity. Keeping others committed to the rules over the long term by employing a friendly rivalry strategy demonstrated to be effective in theory for the n-person PD results in a greater payoff in an evolutionary context [29]. Introducing the informal network and bespoke development framework is a potential mechanism for bridging the formal–informal dimension of inter-agency cooperation in order to facilitate effective inter-agency collaboration [30].

A community-based institution with clear rules has lowered the transaction cost among community members to access water for rice paddy production in Tompobulu [16].

Without clear rules among the community members, rice paddy production will decrease. Although the institution's role still focuses on facilitating resource allocation, it should be easily transformed into a stewardship mechanism for incentivizing nature that benefits both the collective and the environment.

3.2.2. Social Interaction

Ref. [20] examined the formation of collaborative norms with or without the presence of social categorization. They discovered that group members use the following decision rules—reaction, repetition, near-there, and maximum cooperation—to determine the contribution or compensation required for sustaining open-access public goods. The probability of selecting a particular rule depended on the heuristics and the agent's personality as either a committed collaborator, a responsive collaborator, or a reactive player [31,32]. These findings imply that comprehending why and in what contexts certain rules are followed can support cooperation [20,33].

Contrary to the assumption that people will adjust their choice for collaboration (as in [20,34,35] found that intention to cooperate in a group determines the type of cooperator an individual is. The condition includes neighborhoods [36,37]; the strategy of the neighbors [38]; social projection [39–41]; social norms [42], the effect of reciprocity [38]; the affected third parties [43]; historical and social comparisons [44]; dynamic rewiring [45], and commitment to preventing moral hazard [46]. This confirms [41] conclusion that there is no pure cooperator but a conditional cooperator, and a commitment device is needed to keep them committed.

Socio-ecological or indigenous knowledge in Lawu [10], collective rules for contribution in Tompobulu [16], and PES in Cidanau [14] are the commitment devices that shape cooperative behavior. This type of ecological device is missing from the socio-economic governance perspective, it purely enforces legal power as a basis for allocating resources rather than inclusive and equal values and beliefs for accommodating ecological stewardship.

3.2.3. Reward and Punishment

Ref. [47] found that social punishment is more likely to induce norm compliance voluntarily, despite the fact that people's behavior cannot be continuously monitored. They suggest that the induction of norms requires mechanisms or processes to communicate, either for strengthening their salience and efficacy or for enforcing both social approval and disapproval.

Ref. [48] stated that the introduction of punishments would likely increase cooperation. Rewards and penalties do not work on people [49–51]. Their choices and actions are influenced by personal priorities and interests. Cooperation can be increased by punishing defectors and rewarding those who cooperate [50]. A high arrest rate will increase the effectiveness of punishment at discouraging defective behavior, and a low arrest rate will lessen the effectiveness of punishment at encouraging cooperative behavior [48]. Allowing a player to delay or defect while applying a severe penalty will increase cooperative behavior and compliance [52]. Introducing a friendly rivalry strategy is an option for addressing the shortcomings of a rule to continue monitoring the commitments of actors for achieving a long-term cooperative outcome [53].

The community-based practices in Lawu [10], collective actions in Tompobulu [16], and the PES mechanism in Cidanau [14] supported the findings of [47]. Socio-economic governance relies more on financial sanctions than social ones. Integrating the PD perspective in NRM will require the planner, practitioner, and researcher to include and integrate social punishment in the institution regulating the stewardship mechanisms.

3.2.4. Value

The role of value in promoting cooperative behavior is less commonly researched. Social value orientation [54–56] is a factor affecting cooperation. An actor can be classified into four categories: pro-social, pro-self, individualist, and competitor [56,57]. Analysis

of the pro-social or pro-self attitude [55] is important for predicting cooperative behavior based on value orientation.

Ref. [8] criticized the emphasis on monetizing ecosystem goods and services and utilitarian values as underestimated nonutilitarian motives. They suggested a better approach to estimating value achievement based on utilitarian and nonutilitarian values, which could help escape the PD.

Integrating non-utilitarian and social value orientation for projecting cooperative behavior will be the state of the art in advancing policies to address the PD in renewable NRM. Integrating non-utilitarian value into NRM initiatives has been implemented in Cidanau [14] via the introduction of a payment for environmental services (PES). This finding indicates that the local community has an effective solution to protect the nature. The new NRM strategy and approach should adopt this into a formal mechanism for scaling up the impacts.

3.2.5. Uncertainty

Uncertainty, social uncertainty, and the degree of resource depletion thresholds or environmental sustainability negatively affect the level of cooperation in NRM [58]; incentivize the overuse of the resources [59]; and elicit a risk-averse strategy [60,61] among the resource users. Aligning social interaction to reduce uncertainty and increase agent cognition about the behavior of other actors in responding to resource depletion will strengthen the inclination of actors to cooperate. Considering the low transaction cost, the Win–Stay–Lose–Shift strategy allows individuals in an iterative PD setting to escape from a defective situation toward collaboration with limited information [62]. Facilitating information sharing and providing local communities with access to knowledge and documents to enable reflection on a previous action proved effective at establishing and sustaining players' trust [63]. The memory of a player's previous actions or strategies will increase the emergence of cooperation in an evolutionary game [64].

In Indonesia, where the study was carried out, uncertainty about access to community forest areas was a motive for the community in West Papua [17] to find legal recognition. Formal recognition will reduce the local uncertainties about their access, which will lead to stewardship behavior. For policymakers to promote stewardship and cooperative behavior, recognizing the right should be an option to promote the sustainable management of NRM.

3.2.6. Self-Psychology

Psychological nudges [65] and feelings of guilt [66] promote cooperation among actors or agents more effectively than financial incentives do in a PD game theory model. This assertion should be considered when developing an environmental scheme in a context where the market insufficiently incentivizes the value of protected ecosystem services.

Implementing the belief and indigenous environmental knowledge, such as that in the Lawu mountainous region [10], and establishing clear rules for rebuilding trust among the collectives [16] provides empirical evidence that social incentives [65] and feelings of guilt [66] are promising mechanisms for shifting a payoff-oriented institution into a value-oriented one. The absence of this component results in defective behavior, such as illegal logging [11] and farming activities in the tidal swampland [12].

4. Discussion

4.1. PD as an Approach to Solving NRM Challenges

Analyzing NRM as either an allocation or stewardship problem has been useful for investigating the current perspective on approaching this issue. Our review of the 10 selected articles on NRM is presented in the following figure (Figure 2).

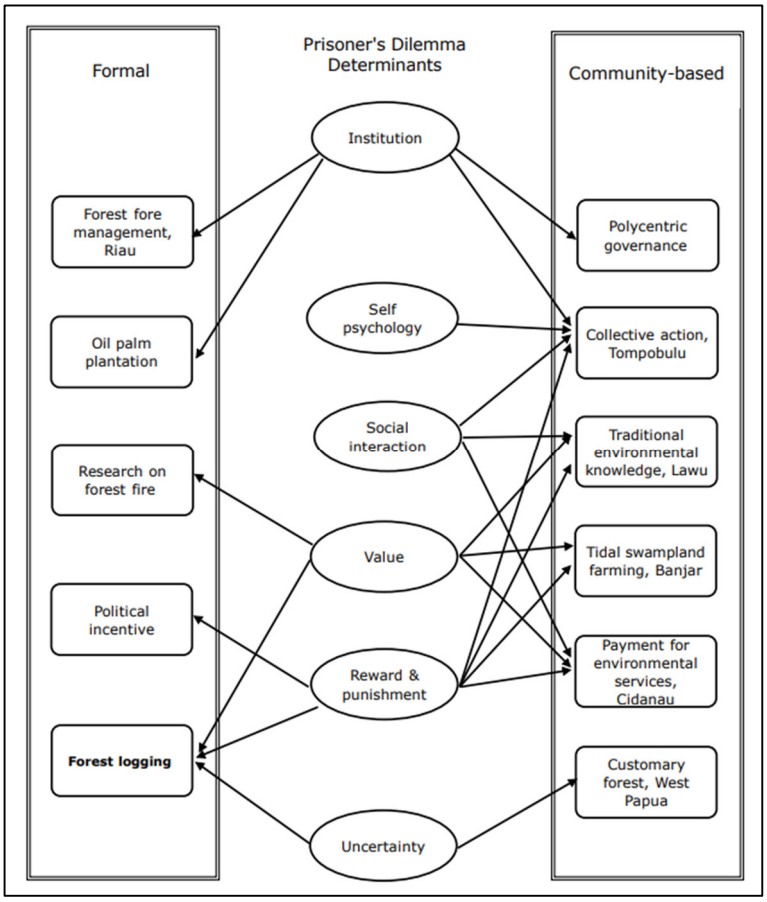

Figure 2. Results of analysis.

The socio-economic governance perspective is the dominant view in interpreting the competition between personal and collective interests in NRM. These findings (Figure 2) indicate that the management of natural resources is more of an allocation problem than one of stewardship. The allocation issues in the studies we reviewed can be classified into three categories: distribution of access by the state to the community as observed in the requests for the recognition of customary forest [17]; distribution of access by the state to individuals (or communities) and corporations such as in the oil palm plantation [11,13,14,19]; and self-access to resources from the communities as observed in tidal swampland management by the locals in South Kalimantan [12].

We identified the mechanisms applied to distribute access to and benefits from NRM practices. The mechanisms are legal [15,17,19], requiring the role of the state as a regulator; a consensus among resource users [16]; a hybrid governance mechanism that combines a legal and a community-based approach [14]; and cultural, which embeds ecological values into socio-ecological practices and narratives [10].

Socio-ecological governance as a new paradigm in NRM in low-transition trajectories is not a dominant perspective in current practices. The application of PES as a financing instrument for resource management in Cidanau [14] is an example of an approach that harmonizes individual, collective, and ecological interests. As in the study on the collective request for the recognition of community forestry [17], the role of institutions in preventing illegal logging [11], and interactions between institutions in managing oil palm plantations [13,16,19], nature is still positioned as the recipient of the impact of the contestation. Ecological interests have not been considered in the case of tidal swampland management [12].

Co-benefits have been dominantly perceived as the distribution of advantages to individuals and groups, the equality of distribution among people, businesses, and col-

lectives [11,13,19], and the distribution of roles, access, and benefits among people in community-based resource management practices [12,16]. In the Lawu mountainous region, eco-cultural wisdom interprets co-benefits as a distribution of the benefits to individuals and collectives [10], while in Cidanau, nature that produces ecosystem services has been treated equally as an entity that has interests equal to those of individuals and collectives [11].

The limited adoption of the socio-ecological governance paradigm in contextualizing, interpreting, and addressing the competing interests among the self, collective, and ecological interests indicate a dire need for a new approach for shaping sound approaches and practices. The intensive use of a socio-economic perspective in analyzing this contestation has serious limitations and should be replaced with a new approach. The competing interests should be framed as both an allocation and stewardship problem. The PD approach is proposed as the choice for addressing the current gap. This approach is flexible enough in defining the role, motive, payoff, and trade-off of self-, collective, and nature interests to be able to bridge the adoption of the good practices that are currently being practiced at the community level on a small scale with formal policies and strategies. Two strategies to address the current gaps in the PD are discussed in the following section.

4.1.1. Transforming the Allocation-Oriented Structure into a Co-Benefit Structure of the Competing and Dilemmatic Interests

This strategy includes the transformation of the normal-form representation of the game by introducing an exit and move option [24] to expand the strategic space of the actor in the game for analyzing the right game structure that is played by the actors. This strategy will enable an observer or policy maker to accommodate the context. Several variations of the structure transformation include agent mobility [37], exit and move options [24,67], and considering a mixed equilibrium in the played PD [68] rather than merely relying on a pure Nash equilibrium assumption.

Making individuals visible in observations will make the outcome of the game more cooperative rather than effective [69]. It is essential to align the objective and the processes in observing behavior to prevent biased results. The formulation of the scope of the goal for the landowner or resource manager will affect their strategy. Agents tend to use a more cooperative strategy in small and local actions than in global [29] actions. The personality profile of the agents or players should be identified in advance, as this will help a researcher to have adequate information to describe the rationale behind the strategy used by an agent or player. Furthermore, social projection [41] is a potential factor to be intervened in to transform the outcome of a PD. The projection can be used to interpret the level of rationality being applied in the game. Social projections made by an agent to their neighbor can be used to test the symmetric and asymmetric levels of information an actor transmits to another. It is reasonable to argue that less asymmetric information about the behavior of other players will lead to the solution of non-cooperative behavior as a strictly dominated strategy. A common assumption in a PD is that a rational player will not play strictly dominant strategies due to asymmetric information and a lack of trust. Information about the social projection will provide a clue to solving the dilemma. The clue provided by [53] is that public communication of social disapproval is a promising strategy to test the validity of changing information symmetry to promote cooperative behavior in a PD of NRM. Information symmetry will also reduce both social and environmental uncertainty [58,59] and prevent the agent from adopting a risk-aversion strategy [60,61]. Assessing inter-agent trust will also help the analyst identify how effective an institution is, which is a step required to measure its capacity to promote a norm for compliance and collective action.

PD has the potential to address the structural gap due to the dominance of the socio-economic governance paradigm in interpreting, planning, and addressing the competing interests of the socio-ecological agents in NRM. Transforming the normative legal view on institutions, strengthening commitment to cooperating in social interaction,

and addressing uncertainties among agents about the situation of ecosystem services are the new approaches to promoting environmental stewardship in the socio-ecological governance of NRM.

Encouraging and promoting polycentric governance that accommodates social trust, reciprocities, and socio-ecological beliefs for enforcing inclusive and equal values and beliefs for ecological stewardship are measures in policies that should be introduced to shift power-oriented institutions into institutions that promote trust among agents and promotes socio-ecological reciprocities. In practices, measures such as the provision of information about the impact of a certain action to ecosystem and recognition ownership will reduce uncertainties to prevent destructive practices in NRM.

4.1.2. Transforming the Socio-Economic Payoff into a Socio-Ecological Value-Oriented Institution

Our review of the cases in this study concludes that the introduction of a financial incentive, reward and punishment, or market-based instruments (MBIs) and social sanctions or punishments are the key themes observed in the psychological discipline that have a high potential to promote sustainability in renewable NRM. Financial incentives have several flaws in promoting the cooperative behavior of a PD problem although it promotes higher collaboration in some contexts [70]. Social disapproval as a form of sanction or punishment will encourage more cooperative behavior than just a financial sanction. Integrating non-utilitarian value (social and ecological value [8], rather than just monetary value is a mandatory step in transforming the PD game outcome. The value of the incentive does not necessarily reflect transaction costs and opportunity costs, which will reduce the attractiveness of the incentives to promote and create cooperative behavior. Feelings of guilt [66] and the impact of a defective action on third parties [43] should be integrated into social value. Constructing an ES or NRM problem in a value game rather than a payoff game is a promising area of research to solve the PD in this context.

Adopting the PD framework will strengthen the current NRM approach from the allocative problem view for maximizing a payoff into an environment stewardship view for addressing a value contestation. Integrating the determinants of the game, such as social punishment, non-utilitarian value, feelings of guilt, impacts on others, and transaction costs, into the current reward and punishment system is an innovative way to address the conundrum caused by the unconclusive impact of reward and punishment in socio-economic governance. Co-benefits should be interpreted and analyzed by accounting for the non-utilitarian value of ecosystems as a payment for social agents, which will contextualize the ecological stewardship principle into a new NRM approach relevant to the nature and characteristics of the low-carbon juncture.

Changing the practices in NRM from the payoff contestation into the competition of socio-ecological value has several implications for practitioners and policy-makers. Firstly, constructing the renewable NRM problem in a PD structure requires practitioners and policymakers to shift their over-optimistic reliance on the normative legal approach of the socio-economic perspective to observing and interpreting the agent's motive and behavior.

Changing the typical monetary disincentive in NRM law and regulation by integrating social disapproval as an innovative approach to bridge the gap between the allocation perspective, the normative legal-oriented socio-economic governance and stewardship view, the view on non-utilitarian value and that on the co-benefit of socio-ecological governance is the measure to be implemented in policies solve the conundrum of the low-carbon transition.

In practice, landowners, public agents, and corporations should consider the transaction and opportunity costs in developing incentive mechanisms to influence the value, rather than the payoff, of defection. The values should include the social cost of non-compliance (feeling of guilt), the non-utilitarian value of the ecosystem services, and the impact on others. Ref. [53] developed a "friendly rivalry" strategy to optimize cooperative

behavior. In practice, this can be achieved by setting up the benefit or loss threshold to ensure an equal distribution of benefits and risks.

4.2. Future Research and Direction

We have shown that PD is a versatile framework and metaphor to portray a competitive interest at the individual level, between individual and public contestation, and among the institution. Our study shows how the versatility of the PD enable it to be a reasoning logic for addressing the flaws of socio-economic governance that assume the rationality of the agent. As a basis for reasoning in analyzing individual and citizen behavior, PD has potential to be applied to address the actual problem in various fields. Several scholars applied PD in sustainability issues such as inequality issues of climate change [71–73]; climate change [1,30,74]; addressing ethical consumption issues in vegan fashion brands [75]; collective action in COVID-19 [72,76]; the framework of analyzing climate negotiation [77]; nature-based tourism management [54]. Trends in applying the PD to real environmental and NRM issues indicate that PD will continue to be a framework for analyzing and formulating solutions for competitive and conflicting human interactions.

On the theoretical side, scholars continue to address the PD's limitations and integrate them with the most recent developments in other sciences. The Win–Stay–Lose–Shift strategy was developed by [62] as the optimal strategy for achieving equilibrium in the game. Ref. [78] evaluated the explanatory power of the PD approach in combination with the preference model in optimizing the utility of human preferences [79]. Ref. [80] examined the stability of defective or cooperative behavior in the PD by conducting experiments with the payoff level. Combining the PD with network analysis [81], assessed the impact of memory in an evolutionary game and [82] assessed the impact of network structure to the cooperative behavior. Ref. [83] developed a novel mechanism based on the heterogeneity of reputation to explore the psychological reasons behind competitive human behavior while [84] based on the result of the experiment, proposed a prisoner's dilemma with personal abstention to create a more realistic view of the PD in the practical realm. Compared to the traditional PD game, the mechanism is effective at encouraging cooperation. Ref. [85] evaluated the effect of payoff by combining the PD approach with the lattice model. The most recent scientific advancements demonstrate the versatility of the PD as a model, framework, and method for analyzing human behavior. The PD is a promising framework for addressing the interdisciplinarity and complexity of human interests in contemporary science and practices due to its versatility.

Considering the trend, versatility of the PD, and the result of this study, we recommend the following research agenda to transform NRM policy and practices in Indonesia to achieve the following low-carbon development objectives.

- Researchers in NRM should shift their focus from the normative legal and allocation-based perspective to the ecological stewardship paradigm by applying the socio-ecological framework in their work.
- Integrating the socio-ecological governance framework in research, policy analysis, and institutional planning to align the renewable NRM with the low-carbon development target and trajectories as this framework acknowledges nature as an entity that has rights that should be integrated in the scope of analysis.
- Promoting a hybrid institution to shape the current payoff-based institution into a value-based institution, taking into account the self, the collective, and the interest of nature in development as shown in indigenous knowledge, practices, and institutions.

5. Conclusions

This study leads to several conclusions. First, the socio-economic governance perspective is the dominant view in interpreting the competition between personal and collective interests in NRM. Mechanisms applied to distribute access to and benefits from NRM include legal, consensus, hybrid governance, and cultural. Co-benefits are seen as the distribution of advantages to individuals and groups, the equality of distribution among

people, businesses, and collectives, and the distribution of roles, access, and benefits among individuals and collectives in community-based resource management practices.

Second, we identified six determinants of the PD that were not recognized from the implementation perspective of socio-economic governance. The first three determinants are related to the structure of contestation (institution, social interaction, and uncertainty), and the second category is payoff-related determinants (reward and punishment, social value orientation, and self-psychology).

We formulated two strategies to address the limitation of applying allocation-oriented socio-economic governance by integrating the PD approach into the socio-ecological governance framework to promote environmental stewardship in the new low-carbon transition. The first is to transform the allocation-oriented structure into a co-benefit structure of competing interests by promoting hybrid governance (polycentric and multi-scalar) that accommodates social trust, reciprocities, and socio-ecological beliefs and reduces uncertainties of ownership and of the condition of resources to reduce defection. The second is to transform the socio-economic payoff into a socio-ecological value-oriented institution by incorporating social and non-utilitarian values, transaction and opportunity costs, the social cost of non-compliance, the non-utilitarian value of ecosystem services, and the impact on others in the reward and punishment mechanisms.

Further work is required to promote the socio-ecological governance framework shown in Figure 1. At the policy level, the integration of socio-ecological governance into NRM policy making and analysis via adopting the environmental stewardship view to address the limitations from the allocation view of the socio-economic governance perspective is a new imperative. In NRM practices, integrating the game theory PD approach into the socio-ecological framework is required to shift the current allocation perspective about NRM to a socio-ecological and stewardship perspective.

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