



Roles and interrelation between variables : a study case of plastic waste management in Jakarta Bay

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Abstract

The accumulation of plastic waste in the marine environment has increased the global risk of marine pollution due to its negative impact on land, ecosystems, and especially the food chain and marine organisms. Ineffective plastic waste management has reduced the quality of the coastal environment including community sanitation and health, landscapes, and coastal views, and influenced economic sectors such as tourism, fisheries, and shipping. The economic and public activities within coastal areas have consistently as the source of plastic waste leakage either directly or indirectly. Various variables involved and connected each other, some influential and other existing variables were not working effectively and do not support each other optimally in the system. The policy without limitation on the plastic production and certain type of plastic such as packaging or single-use, bags, and a lack of management capacity have led to the establishment of a burden on current plastic waste management within the coastal and marine of Jakarta Bay. Therefore, the study aims to analyze the roles and interrelation of variables that influence plastic waste management in Jakarta Bay. Public participation through group discussion, interview, and Micmac analysis method was used to identify, map, and analyze their interrelationships, roles, and hierarchy in the plastic waste management system. The results showed that the dynamics of variables' interaction affect their level of performance and contribution. The variables with strong influence have the potential to strengthen others, while some had a high dependence which was vulnerable to have ineffective performance in the waste management system as their stability relied on other variables' performance. A group of variables were greatly affected by others and indicates that they had lower influence and higher dependence, while the rest of the variables were relatively disconnected from the system. The key to better waste management is to improve the performance and the quality of relationships of variables that were found in the influential and intermediate quadrants. Furthermore, the indirect influence variables also need to be considered as they have the potential to contribute to the future system strategy or scenario planning.

Keywords Marine plastic waste · System · Variables · Micmac · Jakarta Bay

Introduction

The increasing crisis of marine plastic waste has become a global concern due to its significant negative impact on

humans and the environment. The improper management that leads to rapid plastic pollution in the marine and coastal areas has threatened the quality of the ecosystem, coastal sanitation and aesthetics, and human health due to seafood

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consumption containing microplastics. Kaza et al. (2018) have estimated that about 2 billion tons of solid waste are not managed properly, and the number may increase to 3.4 billion tons by 2050. WWF (2019) also estimated that in 2016 plastic waste had reached 396 million metric tons (MMT) or 53 kg of plastic/person, and by 2030 there will be a 40% increase. Other research shows that 150 million tons (MT) of plastics worldwide are in the ocean and will increase by 250 MT if the trends of urbanization, production, and consumption continue (Shuker and Chapman, 2018). Jambeck et al. (2015) also reported that 275 MMT were produced by 192 coastal countries in 2010, and approximately 4.8 to 12.7 MMT/year entered the sea. While Lebreton et al. (2017) estimated that 1.15 to 2.41 MT amount of plastic flows from global riverine areas into the oceans annually.

Nearly 80% of the world's plastic waste is from land-based sources, shorelines, and the sea contains 60 to 90% combinations of different plastic polymers (Andrady 2015; Derraik 2002; Galgani et al. 2015; UNEP 2016; WWF 2019). In Indonesia, the Ministry of Environment and Forestry (KLHK) reported that the national waste production has reached an amount of 67.8 MT/year with 18.5% or 12.54 MT is plastic waste (KLHK 2021). Shuker and Chapman (2018) also reported that an average of 3.22 MT produced waste that was not managed properly resulted in an amount of 0.48 to 1.29 MMT plastic waste leaks into the oceans/year. This range is consistent with other studies conducted by Shuker and Chapman (2018), Cordova et al. (2019), and KLHK (2017) with the amount of 400,000 tons/year, 268.740 to 594.558 tons/year, and 488.096 tons/year respectively.

Plastic waste negatively disrupts marine ecosystems and environmental sustainability including marine food webs, fish, other biotas, and humans' health that consume seafood containing microplastics. The negative impact is widespread and harmful because it is transboundary, persistent at sea, contains hazardous substances, and takes time to decompose. Furthermore, marine biota is also entangled by plastic materials, or plastic waste contaminates coastal vegetation, soil, water, and air (waste burning) with its toxic substances and will have wider damage on marine habitats and ecosystems. These negative impacts have directly affected economic activities such as shipping, fishing, aquaculture, tourism, and recreation (Vince and Hardesty 2016; Shuker and Chapman 2018; UNEP 2017).

The characteristics of semi-enclosed waters with various activities surrounding made Jakarta Bay vulnerable to receiving dumped plastic waste from various sources, such as river outlets, households or settlements, offices, industry, fisheries, ports, and marine transportation. The bay is vulnerable to being a dumping ground of waste leakages from land and sea that are carried by tides into the bay or

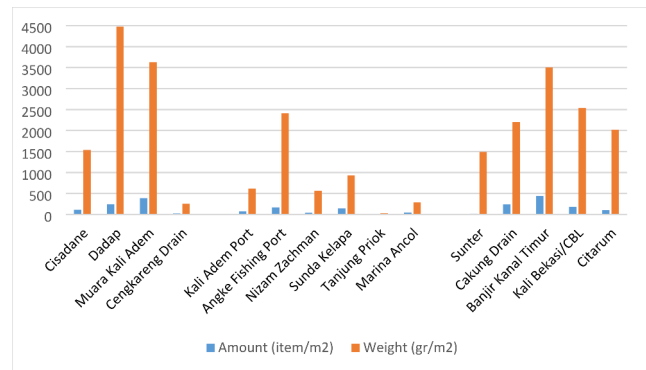


Fig. 1 The type of plastic waste found in Jakarta Bay

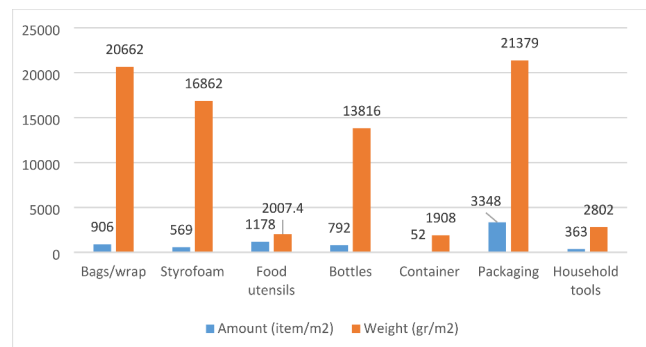


Fig. 2 The type of plastic waste found in Jakarta Bay

estuaries, and the Thousand Islands. The observation conducted in 15 stations of the bay indicates the plastic waste leakage and accumulation occurred in the river mouth and port area (Fig. 1). Dadap, Muara Kali Adem, and Banjir Kanal Timur rivers were the highest, while Angke Fishing Port is highest in the port areas. The type of plastic waste found was dominated by plastic packaging, bags, styrofoam, and bottles respectively (Fig. 2).

The packaging like single-use and plastic bags that are significantly found in the bay area is closely related to plastic production policy and the innovation of plastic types. The critical issues, for example, no limitations on the production and use, the comfortable use of plastics by consumers with a lack of awareness on how to treat plastic waste properly, and limited capacity of the authority in the implementation of prevention and handling instrument are all lead to the establishment of crisis in the plastic waste management in Jakarta Bay. This complexity needs to be unraveled from upstream to downstream to provide an understanding of gaps, what is the most influential variables, and their roles, including their relationship in the management of plastic waste.

The government has declared a 70% reduction of marine debris through the 2018 to 2025 action plan (Presidential Decree 83/2018 concerning Marine Debris Handling), and the National Policy and Strategy (Jakstranas) for the Management of Household Waste and Similar Types of

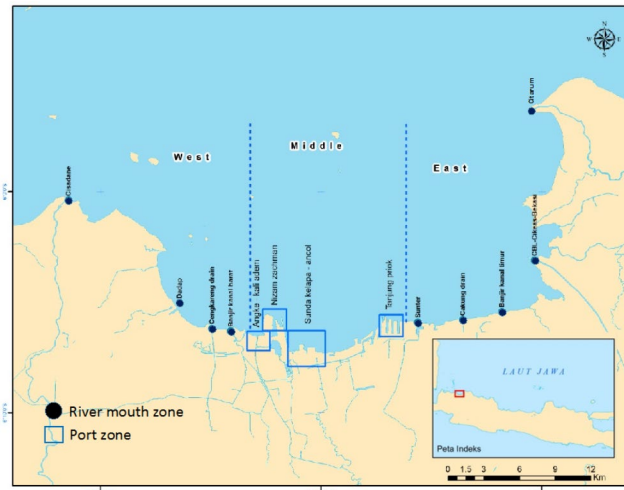


Fig. 3 The study case site of the research in Jakarta Bay

Household Waste (Presidential Decree 97/2017) with the targets of 30% reduction and 70% waste handling through its action plan. These policies derivatives are being followed up by the DKI Jakarta Government Decree 108/2018 at the Regional Policy and Strategy (Jakstrada) level. Ideally, regulatory effectiveness has played an important role in dealing with the complexity of current plastic waste management because it ensures the target can be achieved optimally and effectively. In addition, the majority of variables are reflected in these action plans and become a guideline for related institutions including Jakarta Bay authorities. However, it seems that the implementation of the action plans including its institutional arrangements has not been effective. Hence, the crisis and gaps component then needs to be addressed in the management of plastic waste. It needs the initiative to map the most influential and other existing variables, and their level of relationships, analyze gaps in the implementation of policies, action plans, and instruments, and anticipate the need for policy and scenarios as recommendations for strengthening and improving future management.

Materials and methods

Case study site

As the condition in Jakarta Bay could not be separated from the national context, the study focused on management system both at the national level and in Jakarta Bay. Location of study is presented in Fig. 3. Their dynamic relationships were analyzed because the improvement at the national level directly affects the management at the regional level and vice versa.

Solid waste photos are shown in Fig. 4, showing condition of river mouths and traditional fishing ports which are polluted by solid waste. Composition of solid waste in the west, middle and east zones of Jakarta Bay and its volume is shown in 5. In the middle part mostly fishing and public ports, the plastic waste is not only coming from the estuary and enters the port area by tidal influence, but also significant waste is produced from inside the port by anchored ships, shops, and visitors. Other sources are from outside the estuaries such as marine transportation and floating plastic waste that is carried from other territory seas like Thousand Islands water into the bay waters, estuaries, and ports. The most significant plastic waste found in the eastern part of the bay, followed by the western and middle parts is the least.

Data collection and analysis

The scope of analysis was to identify, map, and classify variables, and to describe their relationship which later provides essential information for system improvements. The Micmac (matrix of cross-impact multiplications applied to a classification) method was used to performs structural analysis through (i) determining key variables, (ii) mapping the relationship between influence (Y) and dependence (X) variables, and (iii) explaining their relevance and causal chain in the system, which among others is used as a reference to unravel and reduce the complexity (Fauzi 2019; Tiwari 2013). The principle of Micmac analysis is mapping the interactions to obtain an integrated picture of variables that have a direct or indirect impact and a detailed display of relationships between elements (Veltemeyer and Sahin 2014). In addition, the key variables are the main or essential factors that affect the system. In the study of the interrelationships between elements, the Micmac method identifies the main influential, dependent variables and explains the evolution of the system through the combination of ideas using a matrix (Godet 2000).

Data were collected through a series of public participation or focus group discussions (FGD) and interviews where experts' and stakeholders' opinions were examined. The participants were representatives from the government (national, regional), experts (academicians, researchers), industries, non-government organizations, associations, and community groups (Table 1). They had various expertise and relevant experiences in plastic waste management such as in the recycling plastic and packaging industry, advocacy, community empowerment, researchers, government officials at the national or regional level in handling day-to-day plastic waste management, particularly in Jakarta Bay.

The explored opinions of experts and stakeholders were used as information for Micmac in analyzing the relationship between variables. The analysis results can be used by



Fig. 4 Waste leakage and accumulation in the river mouth of Dadap (top left) Banjir Kanal Timur (top right), Cakung Drain/Cilincing Fisher Village (bottom left), and in the port area of Muara Angke Fishing Port (bottom right)

policymakers to intervene in the system and to look for alternative strategies as well as action plan formulations (Sahin et al. 2013). In this case, Micmac provides the ranking of variables by measuring the level of influence and dependence and how they interact as a system (Veltmeyer and Sahin 2014). In Fig. 6, the data from FGD (stages 1–2) was analyzed by Micmac (stages 3–4). The identified variables (Table 3) were scored and the outcomes were presented through the MDI matrix (Table 4). The score used to evaluate the influence between variables was 0=no relationship, 1=weak relationship, 2=average, 3=strong, P=potential influence in the future. Based on the Matrix of Direct Influences (MDI) analysis, the Micmac method classified variables into certain quadrants (Fig. 7) based on their level

of influence-dependence (Godet 1994; Fauzi 2019), and its description as shown in Table 2.

The result shows a map of variables that describes the influence and dependence level based on MDI matrix, variables position changes (displacement map) based on indirect relationships, and a hierarchy diagram of variables which both are based on the matrix of direct and indirect influence (MDII). Each variable of the marine plastic waste management system was ranked either by the direct influence and dependence level or indirect influence factor.

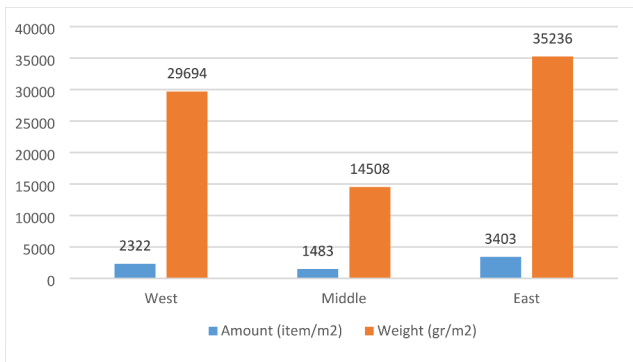


Fig. 5 Composition of plastic waste in the west, middle and east zones of Jakarta Bay

Table 1 FGD participants

Government	Non Government and Institutions
<ul style="list-style-type: none"> • Deputy Environment and Forestry, Coordinating Ministry for Maritime and Investment of Forestry and Environment • Directorate (Dir) Waste Management, Ministry of Forestry and Environment • Dir. Destination Management and Sustainable Tourism, Ministry of Tourism & Creative Economy • Dir. Chemical and Pharmacy, Ministry of Industry • Dir. Ship and Sailor, Ministry of Transportation • Ministry of Research and Technology • Ministry of Home Affairs • Ministry of Education and Culture • Ministry of Marine Affairs and Fisheries • Ministry of National Development Planning • Ministry of Public Works and Housing • Agency Environment of Thousand Island, DKI Jakarta province • Agency of Environment, Banten province • Agency of Environment, Jawa Barat province • Tanjung Priok Port of Jakarta • Muara Angke Fishing Port of Jakarta 	<ul style="list-style-type: none"> • Indonesian Institute of Sciences, Center of Oceanography • National Plastic Action Partnership Indonesia • Nestle Indonesia • Indonesian Olefin, Aromatic, and Plastic Industry Association • Indonesian Plastic Recycling Association • WWF foundation • Kehati foundation • Divers Clean Action • Agency of Assessment and Application Technology • Center for Coastal and Marine Resources Studies, IPB University • Dept. of Aquatic Resources Management, IPB University • Marine Conservation Foundation • National Coordination Task Force for Marine Debris Handling

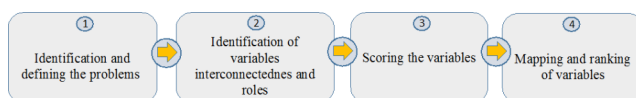


Fig. 6 The stages of analysis using Micmac method

Results and discussion

The variables of the plastic waste management

Thirty relevant variables were identified in the management system of plastic waste and agreed by FGD as shown

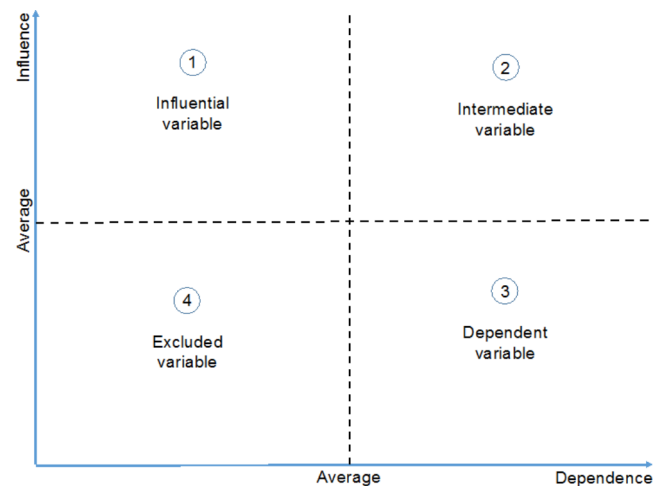


Fig. 7 Variable characteristic and position based on influence and dependence level

Table 2 The description of variables and quadrants

Variable	Characteristic	Implications
Influential (quadrant 1)	High influence, low dependence	<ul style="list-style-type: none"> • Potential as a strong determinant or driver • The changes will affect the dynamics of system and other variable conditions • Potential for planning or changing scenarios and strategies
Relay or Intermediate (quadrant 2)	High influence - dependence	<ul style="list-style-type: none"> • Highly influential on other variables and vice versa (feedback effect) • Critical variable, any actions will create a chain process that affected the system
Dependent (quadrant 3)	Low influence, high dependence	<ul style="list-style-type: none"> • Affected variable and as an outcomes of quadrant 1 and 2, sensitive to the changes in quadrants 1 and 2 • With the high dependence, it needs special attention/study during implementation
Excluded or autonomous (quadrant 4)	Low influence, low dependence	<ul style="list-style-type: none"> • No significant effect on other variables and systems • Relatively disconnected from the system, not determinants for the future system, autonomous character • Possible linkage that might have strong potential

(Saxena et al. 1990; Godet and Durrance 2011; Fauzi 2019)

in Table 3, and all were categorized into five dimensions namely environment, economy, governance, socio-cultural, dan technology based on Micmac method (Godet 1994; Fauzi 2019).

Table 3 Identified variables in the plastic waste management systems

Variables	Number	Description	Dimension
Integrated approach (Integrated)	1	Integrated land-sea based management approach for handling source of leakage	Governance
Volume	2	The volume of plastic waste	Environment
Pilot zone (Pilot)	3	Pilot zone development for better practice	Environment
Environment Quality (Quality)	4	Environment quality and healthy	Environment
Recyclable plastic (Recyclable)	5	The production of easy-to-manage and recyclable plastic inovation including single use	Environment
Production (Product)	6	Plastic production (single-use packaging and bags)	Economy
Business partnership (Business)	7	Business partnership development including informal sector	Economy
Reduction roadmap (Roadmap)	8	Reduction roadmap by producer including plastic bag taxation, bags and single-use limitation	Economy
Packaging product incentive (Incentive)	9	Industrial incentive for easy-to-manage and recyclable product innovation and commitment	Economy
Circular economy (Circular)	10	Reduction based on circular economy	Economy
Stakeholder cooperation (Actor)	11	Multi-stakeholder collaboration	Governance
Government regulation (Govreg)	12	Monitoring the implementation of the government regulation 83/2018 on Marine Debris Handling	Governance
Government support (Support)	13	Government (national-regional level) support (policy, coordination, supervision, fund, infrastructure, capacity building, incentive)	Governance
Packaging guideline (Guideline)	14	Packaging guideline for easy-to-manage and recyclable product	Governance
Policy implementation (Policy)	15	Policy effectiveness including Jakstrada (the action plan of Jakarta government)	Governance
Inter-government coordination and capacity (Intergov)	16	Coordination mechanism of the inter-governmental and their handling capacities	Governance
Standard operation procedure (SOP)	17	SOP on handling sources and impact of leakage in Jakarta Bay including in the marine tourism destination areas	Governance
Law enforcement (Lawnforce)	18	The enforcement of rules, compliance and application of sanctions	Governance
Financial scheme (Fund)	19	Commitment and financial scheme	Governance
Research development (Research)	20	Research development and inovation (packaging, technology), behavior, waste pathways	Governance
Data and analysis (Data)	21	Series and up-to-date data on the source, volume, composition, distribution, impact, handling capacity	Governance
Pandemic covid 19 (Pandemic)	22	The influences of pandemic covid 19	Governance
Management and product certification (Certified)	23	Application of management and product packaging	Governance
Capacity of community (Capacity)	24	The improvement of the community capacity (knowledge, skill, innovation, incentive)	Socio-cultural
Behavior change (Behavior)	25	Community awareness and behavior change including responsibility and participation	Socio-cultural
Local wisdom (Wisdom)	26	The use of local wisdom including cultural belief, packaging material from the nature	Socio-cultural
Infrastructure and facilities (Facility)	27	Infrastructure and facilities fulfillment	Governance
Technology application (Techno)	28	The use of effective and efficient technology	Technology
Added value innovation (Innovate)	29	Innovation and utilization as added value	Technology
Monitoring and evaluation (Monev)	30	Application of monitoring and evaluation system	Technology

The roles and interrelation of the variables

The characteristic of variables in quadrant 1 with high influence and low dependence is influential and has the potential of being a determinant factor in the system (Godet and Durrance 2011). Therefore, their acceleration or performance will greatly affect other variables in quadrants 2 and 3, and on all other variables in the system (Fig. 8 or

Table 5). For example, the variable Product that tends to increase annually would directly increase the number of uses, distributions, and plastic waste in the community and the environment. The variable Product along with the limitations of Facility, Fund and government capacity (Intergov) affect variables in quadrant 2 such as the significant volume of plastic waste (Volume), weak consolidation of interests between pro-industry and pro-environment actors, gaps in

Variable x	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30																			
Variable	Integrated	Volume	Pilot	Quality	Recyclable	Product	Business	Roadmap	Actomive	Circular	Actor	Govreg	Support	Guideline	Policy	Intergov	SOP	Lawnforce	Fund	Research	Data	Pandemic	Certified	Capacity	Behavior	Wisdom	Facility	Techno	Innovate	Money																			
1 Integrated	0	3	2	3	2	2	2	3	2	3	3	2	2	2	3	3	2	3	3	2	3	3	2	3	1	2	2	3	1	3	2	2	3																
2 Volume	1	0	2	3	2	2	2	3	2	2	2	2	2	1	2	3	1	2	3	1	2	3	1	2	2	2	2	2	2	2	2	2	2	2															
3 Pilot	1	2	0	2	2	0	2	2	3	0	2	2	2	1	1	0	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2														
4 Quality	1	3	2	0	2	1	2	2	2	2	2	2	2	1	1	2	3	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2													
5 Recyclable	1	2	0	2	0	0	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2												
6 Product	1	3	2	3	1	0	2	3	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2											
7 Business	1	2	2	2	2	1	0	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2										
8 Roadmap	1	3	2	3	3	2	2	0	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2										
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11 Actor	2	3	2	3	2	2	2	3	2	3	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2								
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22 Pandemic	0	2	1	2	0	1	1	2	0	3	2	2	2	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
23 Certified	1	0	2	2	2	0	0	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
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26 Wisdom	1	0	2	2	2	0	2	2	0	2	0	1	1	1	2	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
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Table 4 The level of influence between variables (MDI Matrix)

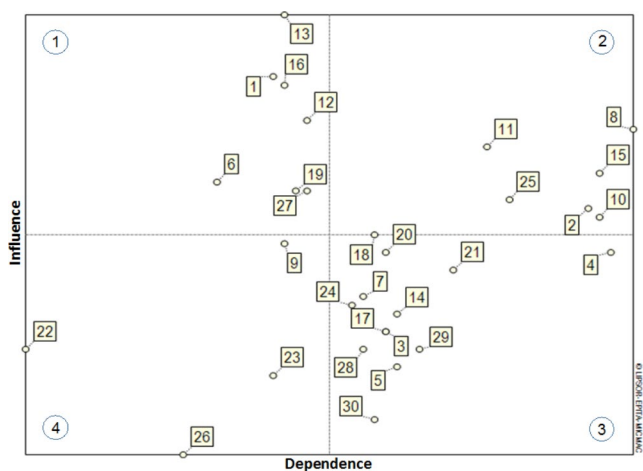


Fig. 8 The variable mapping based on the direct influence and dependence level

Table 5 The group of variables based on their position at each quadrant

Influential Variable (1)	Intermediate Variable (2)	Dependent Variable (3)	Excluded Variable (4)
1. Integrated	2. Volume	3. Pilot	20.
6. Product	8. Roadmap	4. Quality	Research Incentive
12. Govreg	10. Circular	5.	21. Data
13. Support	11. Actor	Recyclable	24. Pandemic
16. Intergov	15. Policy	7.	Capacity
19. Fund	18. Lawnforce	Business	28. Certified
27. Facility	25. Behavior	14. Guideline	29. Wisdom
		17. SOP	Innovate
			30. Money

the implementation of the waste reduction roadmap (Roadmap), and other related regulations (Policy) including the circular economy (Circular). Product design also represents consumers' culture and their high dependence on the use of plastic containers including single-use and bags in situations

where low public awareness occurred (Behavior). However, the performance of variables in quadrant 2 may also have an effect (positive/negative) on other variables in the system, depending on the extent of influence received.

The variables in quadrant 2 with higher influence are also important but their dependence is relatively high such as Roadmap which is essential for waste reduction from the industrial side. On the other side, it is also a challenge for the Actor's solidity in the implementation which sometimes raises questions about the commitment in implementing Roadmap, a package of Policies or instruments. The performance of other variables like Behavior, number of waste in the environment (Volume), Circular economy as an alternative waste reduction strategy, and law enforcement (Lawnforce) are greatly influenced by other variables. Saxena et al. (1990), and Godet and Durrance (2011) identified it as an unstable variable with the potential of becoming a source of conflicts. The possible conflict may arise from the two sides of the Actors' (institutions/companies) interest either to prioritize their mission or show the commitment and responsibility on plastic waste reduction mandated by regulations. The variable with dependence both in quadrants 2 and 3 are affected by these situations. However, some variables in quadrant 2 have the potential of making a positive impact on the system when they run effectively, namely Actors, Behavior, Roadmap, Policy, Circular, and Lawnforce.

The leakage from various sources of waste in Jakarta Bay enables plastic waste to accumulate and spread (Volume), resulting in reduced Quality of the environment. The existing use of technology (Techno) such as fleets of ships, waste collection vessels, and waste nets have not been sufficient for optimal waste handling. The same non-optimal situation occurred on several variables, such as inadequate community knowledge-skill (Capacity) in prevention and handling waste, gaps in the implementation of SOPs, and Guidelines on handling waste from homes and in the environment (coastal, seas, islands, and ports), and inadequate of waste Data. In addition, other variables in the waste management system still need improvements such as the increase of the added value of plastic waste innovation (Innovate), to design easy-to-manage products (Recyclable), empowering and strengthening small-middle-micro business through partnerships (Business), and monitoring and evaluation systems (Money).

The pros and cons of plastic bag taxation and reduction are an indication of the lack of solidity between stakeholders. The continuous accumulation and spread of plastic waste from various sources of leakages made Jakarta Bay vulnerable close to a critical stage of management. A symptom of slow achievement performance is seen from the unfinished ministerial regulation on plastic bags taxation, stakeholders' conflict of interest, continuous plastic waste

leakage into the sea and coastal area. This is a challenge that requires immediate responses, otherwise, permanent burdens will continue to create ineffectiveness in management, which may lead to a millennium 'tragedy of the common' as illustrated by Vince and Hardesty (2018). It needs a systems approach as Eriyatno (2012) with a framework to seek the integration between elements or variables function through a complete understanding of their structure and complex processes, or a cross-scale interaction between element or subsystem that enables communication and cooperation, and also involve actors, information, facilities, techniques, programs, and other support elements (Jackson and Ferris 2012; INCOSE 2006).

As variables in quadrant 2 are strategic, they require maximum management attention. At Cilincing fishing village (Fig. 4), the plastic waste accumulates and spreads in the riverbanks and village environment and the impacts are mainly from some activities such as households, shops, river outlets, and fisheries (fishers, fish market and auction, loading-unloading, docking). The volume of waste is increasing and the environment is filled with litter, among other things because the availability of facilities (trash cans, waste vessels, nets, grinding machines) is not enough for intensive waste collection. The condition also contributed by the role of some variables such as (i) Behavior that disposes of waste improperly, (ii) the insufficient number of personnel and budget (Intergov), (iii) lack of stakeholder engagement in the sea (Actor), (iv) inadequate community participation and capacity (Capacity), and (v) lack of sanctions or fines (Lawnforce). The fishers also argued that inadequate facilities and the low capacity of local authorities were the main sources of the problems. All variables in quadrant 2 were unable to solve the problem independently and required support from other variables, especially from quadrant 1. Therefore, the ignorance of existing conditions will have an impact on the system, and this will lead to dynamics and complexity in management, as well as system instability. At this point, the system may lead to the low accountability of the marine plastic waste management as WWF (2019). However, as Saxena et al. (1990), these variables have the potential to establish a positive contribution to better future management when handled properly and also create a beneficial reverse chain process for the system.

The complexity of the wastes management system requires an approach that examines problems and the behavior of subsystems as it has the potential of being a determinant variable such as Govreg, Actor, Policy, Intergov, Behaviour, and Lawnforce. However, the performance of behavioral change cannot be measured in a short period but rather requires evolution. BPS (2018) reported the Environmental Awareness Index on the waste management category, where 72% of the community have indifferent interest in

waste management. Plastic bags taxation has also received rejections from producers/associations due to the presence of multi-agencies with different missions and interests. The decision-maker needs to work on preventing the instability in the waste management system and the actor variables may be used as important instruments to achieve solidity and effective collaboration.

The millennium of 'tragedy of the commons' in Jakarta Bay can not be avoided if the plastic waste production through various sources of leakages is faster than an existing handling efforts performance, such as producer waste reduction, recyclable products or circular economy, stakeholder cooperation, law enforcement, existing handling capacity, and behavior change. The leakages have not been handled optimally by existing technologies, facilities, application of SOPs and guidelines, community support, law enforcement, and adequate funding. The solution to this condition depends on the ability to fix the performance of highly influenced variables which are mostly in quadrants 1 and 2. In the meantime, as the performance of dependent variables in quadrant 3 will be influenced by their achievement, for example, most variable in quadrant 3 is a part of the variable Govreg action plan (Presidential Decree 83/2018 on Marine Debris Handling). The ability of the National Coordination Task Force on Marine Debris Handling to ensure its effectiveness during implementation is essential, and their success will provide a wider impact to the whole variables in the system.

The government and its hierarchies are the keys to the complexity, system instability, and low accountability as they are connected to all variables. Their effective leadership and responses through coordination, facilitation, assistance, and partnership are needed, and it may be started from the 'government' variable such as Policy, Support, Intergov, Govreg, Facility, Fund, Roadmap, Lawnforce, Pilot, and Incentive. These variables are the key including government support and regulations (Saxena et al. 1990). All efforts that are expected to succeed in its implementation are in a race against time as all sources of leakage continue to produce waste and the amount of plastic waste steadily increases. Pressure on environmental quality continues to grow, while some handling and reduction efforts are still being implemented ineffectively. Therefore, the variables in quadrant 1 with the potential of driving power need to be a priority when considering strategic plans of action (Godet and Durrance 2011), namely Support, Integrated, Intergov, Fund, and Facility as well as Govreg. The strategy may also consider moving their potential influence to another important variable in quadrant 2 for further improvements as they are a potential determinant factor in achieving a sustainable marine plastic waste management system.

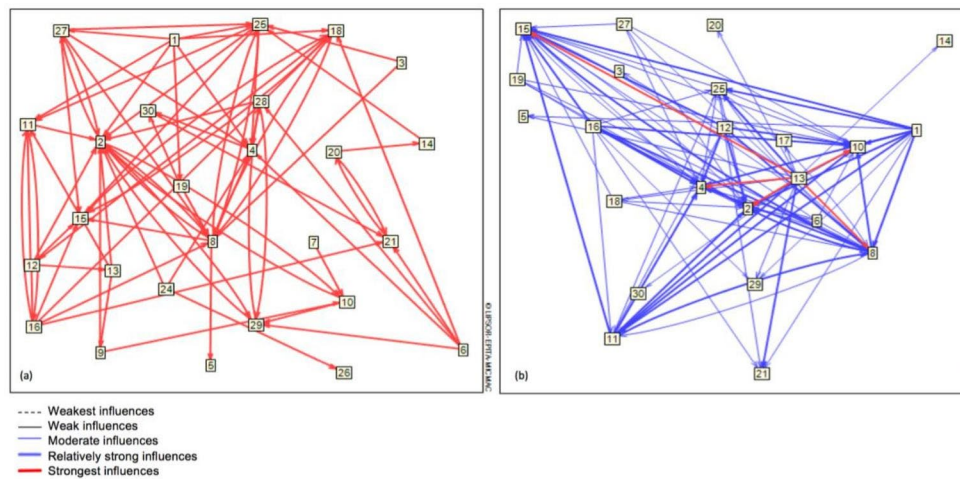


Fig. 9 The relationship level of variables based on direct (a) and indirect (b) influence

The variables in quadrant 4 have relatively less significant effects on others and the system as a whole. With the low influence-dependence, it tends to be disconnected from the system (Saxena et al. 1990; Godet and Durrance 2011), unless several variables are intensified with widespread effects, such as enforcing Incentives for industries to design easy-to-manage plastic products, the application of management-product certifications (Certified), and the use of local community Wisdom. In Jakarta Bay, these variables have not shown a significant effect as instruments but may have the potential to be developed and strengthened. Furthermore, high influence variables may be used to promote the development of the local wisdom approaches through social sanctions or restricting people from throwing garbage into rivers-seas. In the case of Pandemic, the variable is seen by stakeholders as a new situation or a temporary variable where its influence probably will not last permanently and may likely disappear from the system in the future. However, its effects have been seen recently, for example, the limitations on implementing programs that previously involved a large number of participants, like beach cleanup, budget re-focusing policies, and research findings which indicates that there are additional types of plastic waste in Jakarta Bay that come from medical waste. Though this has the potential to slow down the progress of action plans, the implementation of other programs continued even in the midst of the pandemic.

The Level of Relationship Between Variables

The relationship between variables in plastic waste management (Fig. 9a) showed a very strong direct influence of some influential variables such as Govreg, Product, Intergov, and Integrated to the majority of variables in intermediate and dependent quadrant (thick red lines and arrows pointing

out). The level of influence showed the existing management greatly accelerated by the dynamic coordination in the implementation of the Presidential Decree of marine debris handling, the consolidation of the actor on the volume of plastic production and the wider impact of waste to the environment, and the efforts on integrated land-sea based approaches. In addition, some variables (thick red lines and arrows pointing in) such as Volume, Roadmap, Innovate, Lawforce, Behavior, and Quality that strongly influenced by other variables. This condition was indicating that the implementation of several action plans and waste management targets has not been effective. Prevention of waste accumulation, the effectiveness of reduction roadmaps, product innovation, law enforcement, behavioral change, and environmental health cannot be achieved optimally as planned due to their highly dependent nature.

The impact of indirect relationships also needs to be considered as useful information for proper system management. It confirms the importance of certain variables and discovers their potentials, and also their indirect actions which have an important role that is not identifiable through direct classification (Godet et al. 2004). Figure 9b shows variable Support has a very strong indirect influence with future potentials of contributing to accelerate circular economy policies, industry compliance on waste reduction roadmaps, effective policy implementation, and restoration of environmental function and quality, including the achievement of several management targets as mandated by Govreg, Jakstranas, and Jakstrada DKI Jakarta. As the impact of indirect relationships (Fig. 10a), seven variables (ranks 1–7) with high influence remained at the same rank after the indirect factor was included in the calculation. Their stability indicates that in the future these variables are still important in the management system. Eight variables increased in rank namely Fund, Volume, Lawforce, Research, Data,

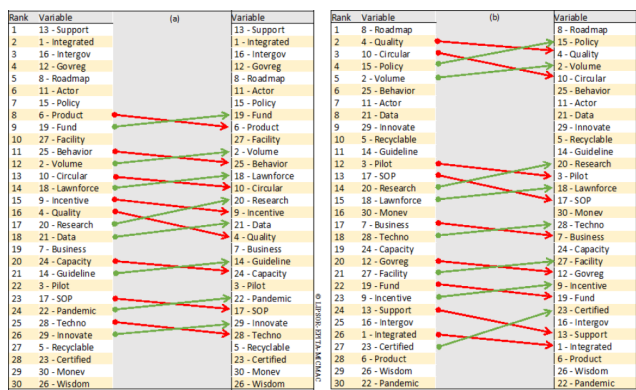


Fig. 10 The shifting order of variables based on influence (a) and dependence (b) after the consideration of indirect relationship

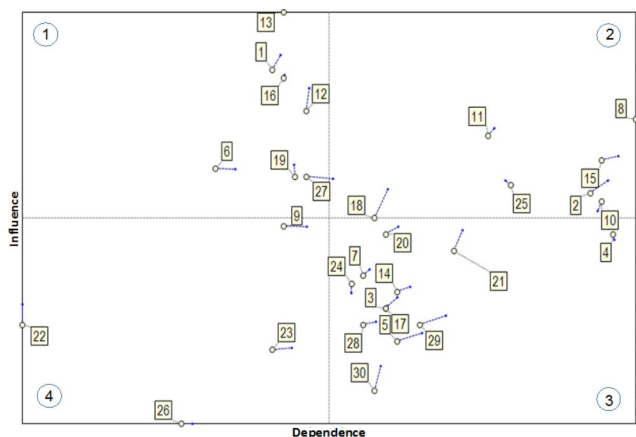


Fig. 11 The shifting of variables position based on indirect influences

Guideline, Pandemic and Innovate. The increased influence of these variables indicates their influence level as they receive a positive impact indirectly from other variables and they have the potential to be considered in future scenarios. In addition, eight variables also experienced a decrease in ranking. On the other side (Fig. 10b), no change of position at the top six rankings, eight variables increased and nine decreased of their dependence rank after the indirect factor was included in the calculation. The increased rank indicates the performance of variables become more dependent on others especially variable Certified, while the decrease indicates the opposite situation, as shown by the performance of variable SOP.

Figure 11 is a replacement map showing the position change of variables in Fig. 10 after the indirect influences were calculated. Furthermore, there were changes in the initial position of the variables in Fig. 8 and this was indicated by the change from a bigger to a smaller circle. Some variables had a change of position in their quadrant, while others shifted to another quadrant. For example, Lawforce (increase in influence) and Facility (increase in dependency) both shifted to quadrant 2. The displacement indicates that

Lawforce has more potential influence in the future with support from certain variables in quadrants 1 and 2. While the Facility variable had more future potential dependence value as the current availability of infrastructure and facilities for plastic waste management mostly relied on the support and facilitation from the national-regional government including some support from other stakeholders such as the private sector and non-government organizations.

Variables improvement and strengthening the systems

The results of the Micmac analysis may be used as a reference to identify areas for intervention or improvement, and this could be carried out in the following ways. First, to analyze some selected variables for further treatment, making improvements, strengthening capacity, and effectiveness. Secondly, to improve the performance of driver-determinant variables in quadrant 1 to increase their effective influence on others, including some important variables in quadrant 2, and enable optimal performance as expected and gradually provide consistent impact to the system. Thirdly, particular attention is needed to explore the hidden potential of indirect influence and dependence variables for their future essential contribution. Fourth, it is necessary to focus more on critical variables and those with high influence and dependence as they are vulnerable to having an impact from other variables (quadrant 2). However, as Godet et al. (2004), these improvement plans may only fit certain parts of the analyzed system that lead to the adjustment of partial improvements. This method of analysis needs to be seen as an indicative approach of illustrating system changes and their essential information, and enable a certain number of potential actions that are planned for further improvements and better plastic waste management in Jakarta Bay. Therefore, as Vince and Hardesty (2018), a single approach may not effectively solve the complexities of environmental pollution and social challenges in the management of marine plastic waste, but rather a comprehensive approach that includes a common will by the public, effective policies, and coordination in the community (global, regional, national, local, and individual levels) including various instruments of action, programs, and regulations.

Learning the roles and interrelation of variables and understanding their influence on the waste management system is an important part of institutional arrangements. As Kooiman et al. (2005), it involves the whole process of public and private interaction to solve problems and create opportunities, including formulating and applying principles that guide the interaction process and encourage institutions to work effectively. Marine plastic waste has continued to increase in recent decades and shows no signs of decreasing

or ending, thereby causing difficulties in reforming existing governance of the variables' dimensions (Dauvergne 2018) as shown in Table 3. Furthermore, the process of environmental recovery and the implementation of resource management is hindered by poor management of plastic waste (Vince and Hardesty 2016) due to the nature of its widespread and transboundary pollution with complexity management. In the long term, it has great potential to reduce the carrying capacity of the environment and threaten the sustainability of marine and coastal resources.

Conclusion

The variables in quadrants 1 and 2 are relatively influential to other variables and the system (all quadrants). They include Support, Integrated, Intergov, Govreg, Product, Fund, and Facilities (quadrant 1), and Actor, Roadmap, Behavior, Volume, Policy, and Circular (quadrant 2). Most of them are government variables or some have received an impact from government intervention. It shows that even though the government efforts are in place but some variables indicated ineffective symptoms due to the performance that is depending on influential or other variables performance. This interdependence and impacted variables can be seen in quadrants 2 and 3 where ineffectiveness is seen through the gap that existed in the policy implementation, inadequate infrastructure, and handling capacity, and low awareness and participation. The plastic production policy with no limitations and ineffective prevention and handling instrument has contributed significantly to an increase in plastic waste in marine and coastal environments. The continued accumulation of plastic waste in Jakarta Bay originating from active sources of leakage indicates the Integrated approach by combining management of waste from land-sea as well as inter-government coordination and capacity still needs an improvement.

As the impact of interdependence and impacted variables, the performance of variables needs support from influential variables. For the higher dependence variables, the solidity of actors in the implementation of management strategy is challenged by different interests, goals, or capacities, for example, the organization's target on profit that influence the commitment, or lack of capacities (facilities, fund, technical knowledge, innovation). It then affects the performance of the roadmap on plastic waste reduction by producers where only a few of them has involved and participated in the proposal submission. The performance of behavior programs is also depending on the performance of other variables such as Actor awareness including consumer, Fund sufficiency, effective Support, Policy, and Lawforce. Though the design of plastic produced like single-use packaging and bags are comfortable for consumers as it is cheap and practical, the

lack of awareness and wisdom on the use of plastic made production contributes indirectly to the accumulation of waste. The Circular Economy approach that is expected to combine both reducing wastes in the environment and offering economic value from waste seems its performance still depends on the support of other variables. Though they are influential, the variables in quadrant 2 tend to be unstable as they perform a high dependence on other variables and are also vulnerable to being influenced by other variable performance.

The main sources of the dynamics of the system are from these quadrants, and their dynamics interaction is also seen in the pros and cons of some prevention or reduction instruments. Therefore, the key to better system management is quadrants 1 and 2 through the improvements of variable performance strategies. The improvements may focus on higher dependence and impacted variables and the effective influence of influential variables. The impact of indirect relationships also needs to be considered as reference information for future system strategy or scenario planning as their potential and importance can be discovered. The Support variable shows a very strong indirect influence on (i) Circular, (ii) Volume, (iii) Quality, (iv) Policy, and (v) Roadmap, and shows the influence and role of government are still very dominant and still needed in the system. In the future, better sustainable management requires a holistic and integrated understanding of performance and the inter-relationships between variables.

Some recommendations that may be used as follow-up research include the study of i) the implementation of gaps in some policies particularly those directly related to marine and coastal areas of Jakarta Bay, and ii) stakeholder role, capacity, and solidity in the plastic waste management system. The results of this study can be used as scientific generic inputs for better future marine plastic pollution management in the bay, which is part of the integrated coastal management of Jakarta Bay. As a tropical bay, Jakarta Bay urgently needs recuperative actions in managing its coastal environment for better bay ecosystem health.

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Statements and declarations

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