

Article

How Indonesia's Cities are Grappling with Plastic Waste: An Integrated Approach Analysis towards Sustainable Plastic Waste Management

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SUPPLEMENTARY MATERIALS

Table S1. MSW data in the case studies [based on the interviews and [1–4]]

Type of data	Bandung city	Yogyakarta city	Magelang city
MSW generation	1600 ton/day	303 ton/day	81 ton/day
MSW composition	45% organic, 17% plastic, 13% paper, 25% others	46% organic, 31% plastic, 17% paper, 6% others	34% organic, 22% plastic, 19% paper, 25% others
MSW contributors	60% H, 13% PF, 10% TM, 17% O	64% H, 18% C, 9% TM, 9% O	74% H, no available data on other sources
Infrastructure	TPS3R, waste bank, RDF facility, landfill*	TPS3R, waste bank, landfill*	TPS3R, waste bank, landfill*
Waste collection rate	80%	88%	75%
Waste reduction rate	19%	25%	20%

H: household, C: commercial, PF: public facility, TM: traditional market, O: Others

*All the three landfills are located outside the city, in the provincial area.

Table S2. List of interviews

No.	Interview code	Interviewee	Date	Location	Duration
1	GOV1	Ministry of Environment and Forestry	June 13, 2023	Jakarta	75 minutes
2	GOV2	Department of Environment and Forestry of Yogyakarta Special Region Province 1	July 05, 2023	Yogyakarta	75 minutes
3	GOV3	Department of Environment and Forestry of Yogyakarta Special Region Province 2	July 05, 2023	Yogyakarta	
4	GOV4	Team Acceleration of Priority Program of Yogyakarta Special Region Province	June 04, 2023	Yogyakarta	75 minutes
5	GOV5	Department of Environment of Bandung City	June 14, 2023	Bandung	100 minutes
6	GOV6	Department of Environment of Yogyakarta City	June 26, 2023	Yogyakarta	75 minutes

7	GOV7	Department of Environment of Magelang City	June 09, 2023	Magelang	150 minutes
8	GOV8	Municipal Government of Yogyakarta City	Aug 11, 2023	Yogyakarta	60 minutes
9	GOV9	Waste Bank Forum of Yogyakarta City	June 24, 2023	Yogyakarta	60 minutes
10	GOV10	Temporary 3R Waste Collection Facility in Bandung	June 16, 2023	Bandung	30 minutes
11	GOV11	Temporary 3R Waste Collection Facility in Magelang	June 27, 2023	Magelang	20 minutes
12	GOV12	Temporary 3R Waste Collection Facility in Yogyakarta	July 17, 2023	Yogyakarta	60 minutes
13	WBC1	Waste Bank Central of Bandung City 1	June 14, 2023	Bandung	30 minutes
14	WBC2	Waste Bank Central of Bandung City 2	June 15, 2023	Bandung	30 minutes
15	WBC3	Waste Bank Central of Magelang City	June 27, 2023	Magelang	65 minutes
16	WBU1	Waste Bank Unit <i>Oh Darling</i>	June 15, 2023	Bandung	60 minutes
17	WBU2	Waste Bank Unit <i>Dabaresih</i>	June 17, 2023	Bandung	55 minutes
18	WBU3	Waste Bank Unit <i>Sembara</i>	June 17, 2023	Bandung	35 minutes
19	WBU4	Waste Bank Unit <i>Bumi Inspirasi</i>	June 19, 2023	Bandung	75 minutes
20	WBU5	Waste Bank Unit <i>Tigo Setunggal</i>	May 28, 2023	Yogyakarta	75 minutes
21	WBU6	Waste Bank Unit <i>Suryo Resik</i>	June 04, 2023	Yogyakarta	60 minutes
22	WBU7	Waste Bank Unit <i>Lintas Winongo</i>	June 24, 2023	Yogyakarta	40 minutes
23	WBU8	Waste Bank Unit <i>Gema Berseri</i>	June 26, 2023	Yogyakarta	60 minutes
24	WBU9	Waste Bank Unit <i>Sulolaras</i>	June 26, 2023	Yogyakarta	40 minutes
25	WBU10	Waste Bank Unit <i>Pelangi</i>	Aug 23, 2023	Yogyakarta	45 minutes
26	WBU11	Waste Bank Unit <i>Bumi Lestari</i>	Aug 25, 2023	Yogyakarta	45 minutes
27	WBU12	Waste Bank Unit <i>Nirwana</i>	July 30, 2023	Magelang	55 minutes
28	WBU13	Waste Bank Unit <i>Bersemi</i>	July 30, 2023	Magelang	60 minutes
29	WBU14	Waste Bank Unit <i>Rukun Makmur</i>	Aug 21, 2023	Magelang	50 minutes
30	WBU15	Waste Bank Unit <i>Bougenville</i>	Aug 21, 2023	Magelang	45 minutes
31	WMC1	Waste Management Company: <i>Daur Resik</i>	June 01, 2023	Online	75 minutes
32	WMC2	Waste Management Company: <i>Rapel</i> (officer 1)	June 23, 2023	Yogyakarta	120 minutes
33	WMC3	Waste Management Company: <i>Rapel</i> (officer 2)	June 23, 2023	Yogyakarta	60 minutes
34	WMC4	Waste Management Company: <i>Rapel</i> 3 (waste collector)	June 20, 2023	Yogyakarta	20 minutes
35	WMC5	Waste Management Company: <i>Duitin</i>	Dec 01, 2023	Online	60 minutes
36	NGO1	<i>Yaksa Pelestari Bumi Berkelanjutan</i> (YPBB)	June 26, 2023	Online	100 minutes

37	NGO2	Indonesia Packaging Recovery Organisation (IPRO) 1	Aug 28, 2023	Online	90 minutes
38	NGO3	Indonesia Packaging Recovery Organisation (IPRO) 2	Aug 28, 2023	Online Online	90 minutes 75 minutes
39	RC1	Indonesian Plastic Recycling Association (<i>ADUPI</i>)	Aug 10, 2023	Online	90 minutes
40	RC2	Plastic Recycler (<i>CV Bina Usaha Mandiri</i>)	Aug 19, 2023	Online Boyolali	75 minutes 165 minutes
41	MM1	Middlemen 1	June 06, 2023	Yogyakarta	15 minutes
42	MM2	Middlemen 2	June 07, 2023	Yogyakarta	60 minutes
43	MM3	Middlemen 3	July 30, 2023	Magelang	30 minutes

Table S3 outlines the key actors in MSW management as identified in the case studies. It is important to note that while there are other significant actors in MSW management, such as the Department of Public Works and Housing responsible for infrastructure development, waste pickers, and itinerant waste buyers, however, the table focuses on those actors that will be explored more in this study.

Table S3. Key actors involved in MSW management within the case studies [based on the interviews, local regulations on MSW management, and [5]]

Key actors	The roles
Department of Environment	Serves as the primary executor of MSW operations, including waste handling, service, and reduction efforts; educates the public; and develops the MSW system.
TPS3R	Collects mixed-MSW, segregates it, processes organic waste, and transports inorganic waste to middlemen or recyclers.
Waste Bank Central	Gathers recyclable waste from waste bank units, individuals, schools, offices, and businesses.
Waste Bank Unit	Collects recyclable waste from the community in a neighborhood area.
Private Waste Management Company	Represents the private sector in waste collection, focusing on recyclable materials, often utilizing digital platforms for efficiency.
Middlemen/Dealers	Operate in the private sector, formally or informally, purchasing waste from waste banks with minimum weight requirements, sorting the materials, and then selling them.
Recycling Industries	Purchase sorted waste from middlemen/dealers/private waste management companies and process it for recycling.

Table S4. Interview questions

Interview question for municipal government
1. To what extent is the role of local government in waste management?
2. Where does the budget for waste management in this city come from?

3. What are the local regulations regarding waste management?
4. What is the hierarchy of waste management in this city?
5. About the waste system components
 - What is the official procedure for handling household plastic waste?
 - What percentage of waste is sorted?
 - Do you think the plastic waste management system in this city is efficient?
 - What is the price range for waste management per household per month?
 - What percentage of household waste can be collected?
 - What are the types of resource management in this city? Why?
 - What percentage of waste goes to the landfill?
 - What type of landfill is currently in use? What are the future plans for the landfill?
6. Regarding the plastic waste processing & treatment system
 - What technology is used to process waste?
 - What is the recycling percentage in this city?
 - How is the development of EPR policy enforcement?
 - What is the situation of the recycling market in this city? Are the prices fluctuating?
7. Is there any waste management collaboration with external parties?
 - What are the current challenges in waste management between parties?
 - Are there efforts to integrate the informal sector into the waste management system?
 - What is the structure of waste bank in this city? How many WBUs are there?
8. What have been the impacts of waste management on the environment and public health so far?
9. How is the transformation of the waste system towards sustainable development?
 - What are the strengths and weaknesses of plastic waste management in this city?

Interview question for national government

1. What is the role of the MoEF in the waste management system?
2. What are the synergies and challenges of inter-agency cooperation in creating sustainable waste management?
3. Has the national budget been sufficient for waste management so far?
4. What is the hierarchy of policy implementation down to the city level?
5. How is the development of EPR in Indonesia?
6. What efforts have been or will be made by the central government to address plastic waste?
7. What is the plastic recycling rate in Indonesia currently?
8. In your opinion, is plastic waste management in Indonesia efficient? What are its strengths and weaknesses?
9. Could you explain about the waste bank initiative?
10. What infrastructure is currently being developed or will be developed?
11. What efforts are being made to integrate the informal sector into the formal sector?
12. What are the central government's strategies for creating an integrated and sustainable waste management system?

Interview question for TPS3R

1. Since when has the TPS3R been established?
2. What types of waste are accepted, and from where?
3. What is the process flow for plastic waste at TPS3R?
 - To where is plastic waste transferred, and into what does it get transformed?
4. How many kilograms of plastic waste are recovered per day?
 - Which type of plastic waste is collected the most?
5. Which types of plastic waste can be sorted and recycled, and what percentage is this?

6. Do you think that people are more inclined to sort waste now compared to the past? What challenges are faced in processing waste at TPS3R?
Interview question for waste bank
<ol style="list-style-type: none"> 1. When was the waste bank established? What activities are currently underway? 2. How does the waste collection system work at this waste bank? Does the committee conduct further sorting? 3. How many members does this waste bank have on an RT/RW scale? What percentage of households are members? 4. What form of support does the local government provide to the waste bank? 5. What type of plastic is most collected? What type of plastic is rejected? 6. Is there any data on the amount and composition of waste from 2019 to 2023? 7. Where does the income for the waste bank management come from? 8. How do you deal with the fluctuation of plastic prices? 9. What are the driving factors in managing the waste bank? Any challenges? 10. In your opinion, what influences whether people choose to join or not join the waste bank? 11. Are people willing to collect waste according to the regulations? 12. What do you think about the plastic waste management system in this city? Any suggestions?
Interview question for waste management company
<ol style="list-style-type: none"> 1. About the company <ul style="list-style-type: none"> • When was this company established, and what activities are currently being undertaken? • Where is it currently operating? • How many clients does the company have? • What digital solutions are used? 2. How is this company's relationship with the city or national government? <ul style="list-style-type: none"> • Is the service provided by this company integrated with waste management in the formal sector? 3. What is the material recovery flow? Who are the stakeholders involved in the system? 4. Regarding plastic waste, how many kilograms of plastic waste can be collected per day? 5. What type of plastic is most collected? 6. Of the plastic waste received, can all of it be recycled? What recycled products are produced? 7. Of the collected plastic waste, what packaging is most difficult or impossible to recycle? How is this addressed? And what types of plastic packaging are already being recycled in large quantities? 8. How does this company cope with the fluctuation of plastic prices? 9. What drives the efforts to handle plastic waste? What are the challenges in current practices? <ul style="list-style-type: none"> • If looking at the processes of collection, transfer, and treatment, have there been any challenges? 10. What is the current condition of plastic recycling in Indonesia? What are its advantages and disadvantages? What areas need improvement? 11. Indonesia has a target of reducing waste by 30% by 2025, in your opinion, how does this affect the recycling business in Indonesia?
Interview question for NGO
<p>For NGO1:</p> <ol style="list-style-type: none"> 1. What is the role of NGOs in the plastic waste management system in the city of Bandung/Indonesia? <ul style="list-style-type: none"> • What are the challenges in coordinating among stakeholders in waste management? • Could you explain the zero waste cities program initiated by YPBB in Bandung City? Is there a conceptual scheme for it? 2. What is your opinion on the plastic waste management system in the city of Bandung/Indonesia? <ul style="list-style-type: none"> • How is it developing towards an integrated and sustainable system? • In your opinion, what are the challenges of plastic waste management in Indonesia? What is lacking, and what needs need to be developed?

- Why do you think it is not easy to enforce waste separation regulations in Indonesia?
3. Regarding the government's target for the reduction and management of plastic waste, do you think this can be achieved? How has it progressed so far?

For NGO2-3:

1. What are the roles and responsibilities of IPRO in the recycling system in Indonesia?
2. What challenges has IPRO faced in its role as a 'mediator' in the recycling packaging chain?
3. What types of packaging are accepted?
4. Who are IPRO's partners in recycling packaging? How does IPRO select its partners?
5. How does the government support IPRO or the packaging recycling industry in general in Indonesia?
6. What is the current condition of plastic recycling? What are its advantages and disadvantages? What areas need improvement?
7. Of the packaging (especially plastic) produced by IPRO members, which packaging is the most difficult to recycle? How is this addressed?
8. Indonesia has a target to reduce waste by 30% by 2025; how does this affect the recycling business in Indonesia?

Interview question for recycler

For RC1:

1. What are the roles and responsibilities of ADUPI in the waste management system in Indonesia?
2. How is ADUPI's relationship with the national government?
3. What is the current state of plastic recycling? What are its advantages and disadvantages? What improvements are needed?
4. How does the government support the recycling industry in Indonesia?
5. Currently, which types of plastic can be recycled in large quantities in Indonesia? And which types of plastic are difficult or cannot be recycled?
6. What are the main issues with plastic waste in Indonesia?
7. Indonesia has a target of reducing waste by 30% by 2025; how does this affect the recycling business in Indonesia?

For RC2:

1. What is the role and responsibility of this business in plastic waste management?
2. Can you describe the business model? Who are the parties involved in the system?
3. How is the relationship with the city government? Is there support or conflict?
4. How do you handle the fluctuation of plastic prices?
5. Which areas does this business cover?
6. What is the flow of plastic waste?
7. What is the plastic recycling process?
8. In the processes of collection, transfer, and treatment, have there been any challenges so far?
9. What types of plastic waste are accepted and what will they be recycled into? Are there any specific products required to support the business?
10. So far, which plastics have been the most difficult to recycle, and which are easy and in high demand?
11. What are your expectations for the plastic waste management system in Indonesia? What kind of government support could assist recycling business operators?

For both:

In your opinion, what is the current strategy of the recycling system in Indonesia? What needs improvement?

Interview question for middlemen

1. What is the flow of plastic waste? Who are the parties involved?
2. Where do the sources of waste come from?
3. What areas do you cover?

4. What is your relationship with the local government?
5. How much plastic waste can you collect per day? What percentage can be recycled?
6. What type of plastic waste is most collected and what is rejected? What are the recycled products?
7. Compared to the past, are more people sorting waste now?

Table S5. Plastic waste recovered through waste banks in the case studies (tonnes per year)

Bandung			Yogyakarta			Magelang		
Year								
2020	2021	2022	2020	2021	2022	2020	2021	2022
703,2	568,9	939,1	1,8	1,8	2,2	7,4	10,8	11,6

Table S6. Types of plastic waste accepted in the waste banks

No	Case Study Location	Type of Plastic Waste	Example of products
1	Bandung City	Soft plastics	plastic shopping bag, transparent plastic bag
		Thick plastics	shampoo bottle, cleaning product bottle, PET bottle cap, jerry can, gallon cap, beverage cups, plastic basket
		Hard plastics	plastic hose, drainage pipe, hard food containers, <u>styrofoam</u> , yakult bottle
		PET bottles	beverage bottles
		Others	gallon bottle, compact disk
2	Yogyakarta City	Soft plastics	plastic shopping bag, transparent plastic bag
		Thick plastics	shampoo bottle, cleaning product bottles, concrete mixing bucket, beverage cups, plastic basket, water dipper
		Hard plastics	Drainage pipe, plastic hose, rubber boots, hard food container, helmet, thermos
		PET bottles	Beverage bottles
		Others	gallon bottle, compact disk
3	Magelang City	Soft plastics	plastic shopping bag, transparent plastic bag, <u>multilayer plastics packaging</u>
		Thick plastics	shampoo bottle, cleaning product bottle, PET bottle cap, beverage cups, plastic basket, jerry can, water dipper
		Hard plastics	drainage pipe, yakult bottle, plastic toys
		PET bottles	beverage bottles
		Others	gallon bottle, compact disk

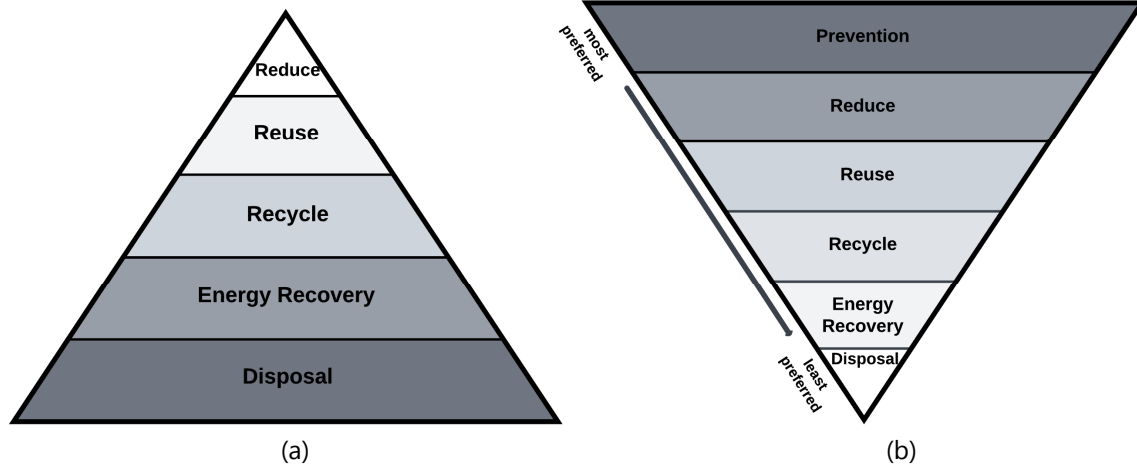


Figure S1. Common practice of waste management in developing countries (a), and the waste management hierarchy towards sustainable development (b) [6]

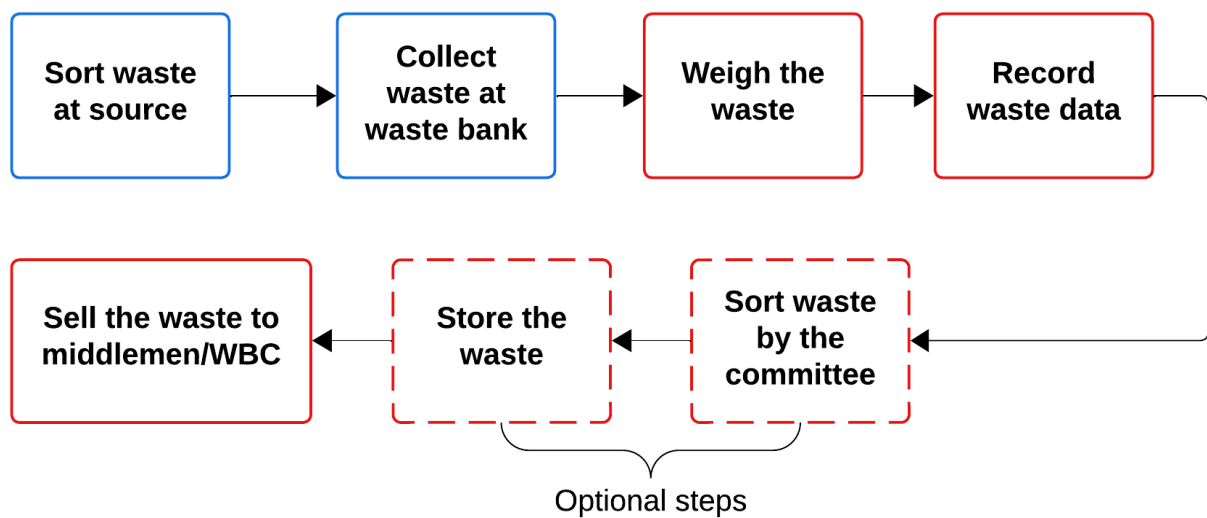


Figure S2. The waste collection process at WBU in the case studies. The blue color indicates the role of the community, while the red color denotes the role of WBU.



(a)



(b)

Figure S3. Plastic wastes collected at Bersemi waste bank in Magelang City (a), a middleman picked up the waste from a WBU (b) (own photograph, 2023)



(a)



(b)

Figure S4. Weighing the plastic waste in Oh Darling WBU (a), the waste bank committee sort and clean the plastic waste in Sembara WBU (b) (own photograph 2023; Sembara waste bank photograph, 2023)



Figure S5. The corner to promote handicrafts by local waste banks inside the DoE of Yogyakarta City (own photograph, 2023)



(a)



(b)

Figure S6. Handicrafts by local waste banks in Yogyakarta (a) and in Magelang (b) (own photograph, 2023)



Figure S7. A grocery stall in Bougenville waste bank in Magelang City (own photograph, 2023)

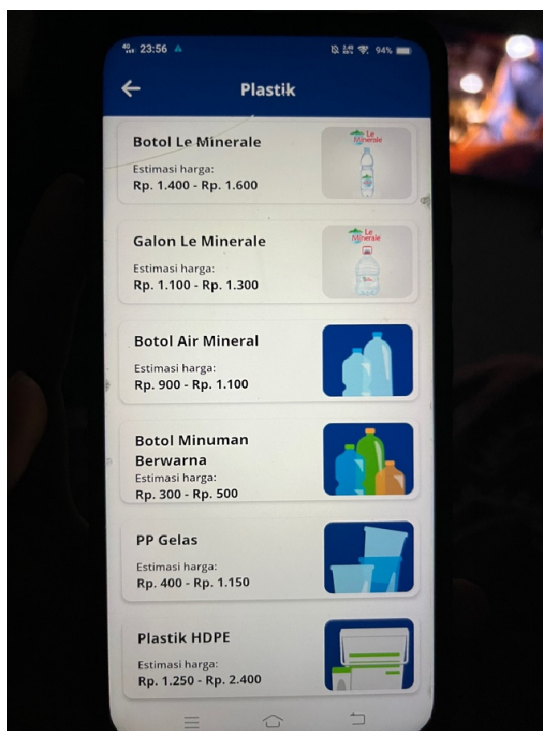


Figure S8. The Rapel waste management mobile apps (own photograph, 2023)



(a)



(b)

Figure S9. A pushcart (a) and three-wheel vehicles (b) to transfer waste from households (own photograph, 2023)



Figure S10. PDU Cicabe to sort and store plastic waste in Bandung City (own photograph, 2023)



Figure S11. Waste collection by Rapel (own photograph, 2023)



Figure S12. Waste collection by Daur Resik (own photograph, 2022)



(a)



(b)

Figure S13. The pile of multilayer plastic packaging waste (a) and a recycled-product of multilayer plastic waste (b) in CV Bina Usaha Mandiri in Boyolali, Central Java (own photograph, 2023)

National law	Act No. 18/2008 on Solid Waste Management	
Government Regulation	Government Regulation No. 81/2012 on Management of Household and Household-like Waste	
Presidential Regulation	Presidential Regulation No. 97/2017 on National Policy and Management Strategy of Household Waste and Household-like Waste (JAKSTRANAS)	
Ministerial Regulation	MoEF Regulation No. P.75/2019 on Roadmap to Waste Reduction by Producers	MoEF Regulation No. 14/2021 on Waste management in Waste Bank
Local Regulation	<div> <div> Bandung City <div> <div>Local Regulation No. 17/2012 on Plastic Bag Reduction & Mayor Regulation No. 37/2019 on the instruction of implementation of Local Regulation No. 17/2012</div> <div> <div>Local Regulation No. 9/2018 on Bandung City Waste Management</div> <div>Mayor Regulation No. 74/2021 on Bandung City Solid Waste Master Plan</div> </div> <div>Mayor Regulation No. 1426/2018 on Bandung City Policy and Strategy of Household Waste and Household-like Waste (JAKSTRADA)</div> </div> </div> <div> Yogyakarta City <div> <div>Local Regulation No. 10/2012 & No. 1/2022 on Yogyakarta City Waste Management</div> <div>Mayor Regulation No. 32/2022 on Yogyakarta City Solid Waste Master Plan</div> </div> <div>Mayor Regulation No. 67/2018 on Yogyakarta City Policy and Strategy of Household Waste and Household-like Waste (JAKSTRADA)</div> </div> </div> <div> Magelang City <div> <div>Local Regulation No. 10/2013 on Magelang City Waste Management</div> <div>Mayor Regulation No. 06/2022 on "Magelang Cantik" Program</div> </div> <div>Mayor Regulation No. 30/2019 on Magelang City Policy and Strategy of Household Waste and Household-like Waste (JAKSTRADA)</div> </div>	

Figure S14. Summary of Regulation of MSW (Adapted from [7], modified by the author)



(a)



(b)

Figure S15. Mixed plastic waste in a TPS3R in Yogyakarta (a), and divided bins in a TPS3R in Magelang City (b) (own photograph, 2023)



(a)



(b)

Figure S16. Plastic waste cleaning and sorting activities at a waste bank (a) and open space storage at a private waste management company (b) (own photograph, 2023)



(a)



(b)

Figure S17. The underused sorting facilities in PDU Bandung City (a) and the conveyor belt facilities in TPS3R Yogyakarta City (b)



(a)



(b)

Figure S18. The compressing machine for PET bottles in PDU Bandung City (a) and shredded plastic waste product in WBC Bandung City (b)

References

1. Department of Environment of Bandung City: Laporan Kinerja Instansi Pemerintah DLH Kota Bandung 2022. (2022)
2. Department of Environment of Magelang City: Neraca Sampah Kota Magelang 2022. (2022)
3. Jatmika, B., Sekito, T., Dote, Y., Subanu, L.P.: Community-Based Waste Management in Magelang Municipality Indonesia. (2016)
4. Ministry of Environment and Forestry of Indonesia: Waste Composition in Indonesia, <https://sipsn.menlhk.go.id/sipsn/public/data/komposisi>
5. Lestari, A.P., Bijaksana, A.F., Ibrahim, R.M.: The Governance of Solid Waste Institutions in Indonesia, <https://waste4change.com/research/the-governance-of-solid-waste-institutions-in-indonesia-part-ii-regional-government?lang=en>, (2019)
6. Pariatamby, A., Fauziah, S.H.: Sustainable 3R Practice in the Asia and Pacific Regions: The Challenges and Issues. In: Pariatamby, A. and Tanaka, M. (eds.) *Municipal Solid Waste Management in Asia and the Pacific Islands: Challenges and Strategic Solutions*. pp. 15–40. Springer Singapore, Singapore (2014)
7. Ministry of Environment and Forestry of Indonesia: National Plastic Waste Reduction Strategic Actions for Indonesia, <https://www.unep.org/ietc/resources/policy-and-strategy/national-plastic-waste-reduction-strategic-actions-indonesia>, (2020)