Research Article

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Developing a plastic cycle toward circular economy practice

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Abstract: This study develops a plastic cycle toward circular economy practice in Vietnam. First, we analyze inter-relationships between economic sectors and environmental issues concerning plastic waste in 2018. The research method integrates interdisciplinary balance with life cycle inventory, in which input–output (IO) table is both an econometric tool and original database to determine plastic IO between industries. As a result, over 60% of plastics after use was recycled for the production process (called recycled plastics) and nearly 40% of plastics after-use left the process (called disposed plastics). Within the recycled plastics, there was 10–15% of informal recycling collection from trade villages; within the disposed plastics, there was 13–18% unable to be collected and uncontrollably disposed to the environment. Then, we construct the plastic cycle, in which all the imported/domestic flows, single/multiple uses, and recycle/disposal flows are represented in proportional dimensions. This overall yet quantitative picture is an important data-driven basis for proposing plastic waste management solutions toward circular economy practice. As analyzed, the most challenge for waste management in Vietnam is to control single-use products (occupied 15.96% of total plastics) and indiscriminate waste in the environment (occupied 20.36% of total plastics). The case study for polyethylene terephthalate shows the need for expanding producer's responsibilities to improve plastic recovery efficiency.

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1 Introduction

The transformation of the development model from a traditional linear economy to a circular economy has become a trend and Vietnam does not stand aside from that trend. This is the total approach method aiming to increase the manufacturing cycle and break through the long since constraint between economic growth and negative effects on the environment [1,2]. Therefore, in this transforming process, nations around the world are having to choose suitable economic sectors to improve the quantification of waste flow in the whole supply chain and choose agreeable management solutions.

Vietnam's plastic industry is experiencing rapid productivity growth, approximately 11.6% in the period 2012–2017, while the GDP of the sector accounted for 6.7% GDP of the country in 2018 [3]. According to the approved master plan for the development of the plastic industry, it encourages to make the industry self-sufficient in raw materials and produce environmentally friendly plastic products to meet the domestic and export requirements [4]. Particularly, imported polypropylene (PP) material is increased through preferential tax rates [5]. In Vietnam, domestic plastics are produced at both plastic factories and plastic recycling trade villages. Because of the high recovery ability of the plastics after use, the plastic sector has a natural correspondence with the circular economy practice. However, plastic collecting and recycling activities are still carried out informal and on small scale. Publications in the period 2011–2014 show that the average quantity of plastic waste generated from plastic factories in an industrial zone in Binh Duong, the biggest industrial city in Vietnam, was 129.3 kg per ton of plastics [6]. Regarding the plastic recycling craft villages, the plastic waste generation rate was ranged from 8 to 11.2 kg per ton of plastic [7]. Aside from plastic waste generated from production activities, the misuse of plastics, especially persistent nylon bags and

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disposable plastic products, has caused a huge amount of plastic items after use wasted indiscriminately into the environment. Recently, the WWF's research carried out for four Vietnam cities including Ho Chi Minh City, Da Nang, Quang Ninh, and Rach Gia showed that the average recycling rate of plastic waste was 22.45% and the average disposing rate of plastic waste was 12.48% [8]. Using the same method, the result by Stockholm International Water Institute carried out for Vu Gia-Thu Bon River Valley showed that the average recycling rate of plastic waste was 17.12% [9]. Focusing on the disposal of polyethylene terephthalate (PET), the genetic algorithm circular analysis has researched the recovery rate of PET waste [10]. Nevertheless, all the studies have not considered factors of interdisciplinary between economic sectors and a value chain of the plastics sector. As in many other countries, plastic waste matters have been incorporated into strategy systems as well as regulated in legal documents in Vietnam [11], but the structuring basis for data-based waste management solutions still needs to be elaborated.

In the world, there are two approaches toward circular economy practice: (i) approach by systemic economy-wide implementation and (ii) approach by group of sectors, products, materials, and substances [12]. In the second one, nations decide on certain materials and determine groups of industries related to those materials to be prioritized in waste management. This approach is not restricted by space and has been affirmed by World Economy Forum that "material is the largest common denominator of all industries and geographical space" [13]. Input–output (IO) analysis is one of the methods that allow quantifying materials consumed and waste generated by all industries in an economy. The IO table was first developed by Leontief to analyze the link between industries and consumers, which is presented by a system of linear function between values of output products and input services with structural coefficients decided by technological processes. Since then, hundreds of countries around the world have built up their IO tables [14–16]. Expanding for waste analysis, the waste IO table has been developed and used effectively to research the relationship between waste recirculation and economic activities [17–20]. Since the 2010s, some research has integrated the IO table and/or the waste IO table into life cycle inventory, whereas the tables can exploit industries and the life cycle analysis can exploit a specific material or product [21–24]. In this study, we use these tools to jot down three research questions: (1) the amount of plastic waste in Vietnam and how are they being produced, (2) issues and challenges in handling them, and (3) solutions for recycling. The plastic waste cycle will be built up and from that basis to orientate resource-effective solid waste management solutions for the plastic sector in Vietnam.

2 Research methodology

The waste IO table shows inter-relationships among goods/services and waste of an economy, in which waste is divided into "waste" and "effluents" [23]. For example, municipal solid waste belongs to "waste" because it is collected, processed, and gone into landfills while the wastewater from production activities belongs to "effluents." In our previous study, the 2018 waste IO table is developed based on the 2018 IO table, which was updated from the original 2012 IO table, and aggregated into 40 sectors including 37 economic sectors and 3 waste sectors [19]. The upper part of Figure 1 shows the structure of the table with 40 sectors. The volume of solid waste landfilled is considered "environmental burdens" as these are the final form of waste in the environment. In the table, the upper block consists of rows representing good/service categories and columns representing industries, solid waste, and end-users. This block shows the cross-sector flows, each X_{ij} of which represents the quantity of good/service i demanded by industry j. Production and consumption activities generate wastes. The middle block consists of "waste" rows and "industry" columns representing waste loads generated by industries. For example, WC_{37} represents the amount of hazardous waste generated by the products manufacturing industry. The amount of wastes generated from consumption activities is represented by W_{if}, (i = A, B, C) of the column "final demand." Within the waste IO framework, the field of solid waste treatment is represented by the processes of converting solid wastes, and the activity of waste recycling is represented by a negative value (−). The "burying" activity creates a "landfill volume" of E_{40}. Labor costs and values added are represented by L_i and V_i, respectively.

The research method is illustrated in Figure 1, which drives toward the use of an economic mathematical model for supporting a quantified analysis of plastic waste flows.

To get plastic demand (PD) (including intermediate consumption, ID_i, and final consumption, FD_i) and plastic outputs (PO) (including plastics exported, EX, and excluding plastics imported, IM), the 2018 water IO table is converted into the table of hybrid units, in which the plastic sector (S16) is compiled in its physical unit (ton of plastics) through producer's prices. Focusing on seven plastic material

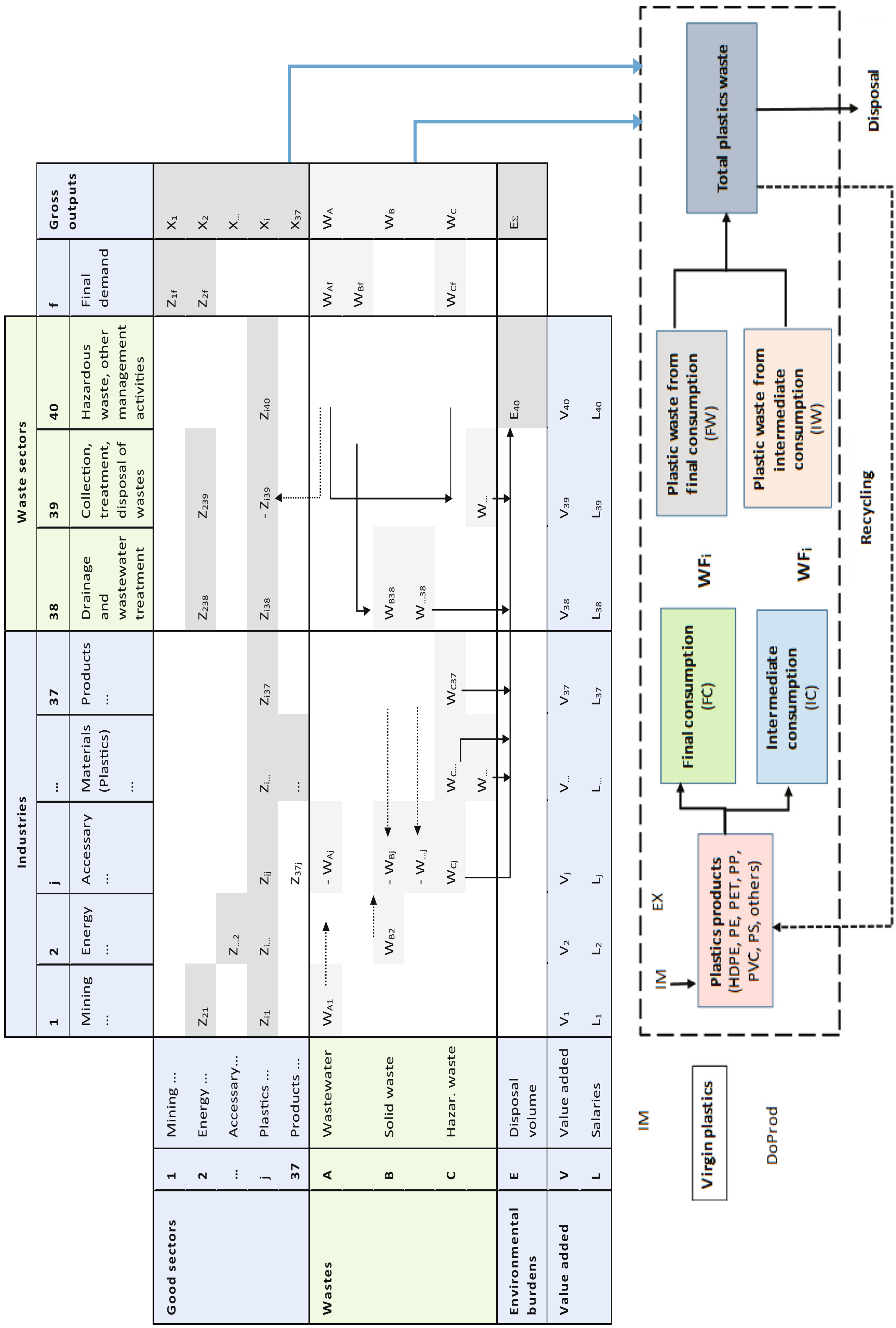

Figure 1: Research method.

categories including high-density polyethylene (HDPE), polyethylene (PE), PET, PP, polyvinyl chloride (PVC), polystyrene (PS), and others, our investigations and experiments are carried out at production facilities and disposal landfills, respectively, to determine the plastic waste generation fraction from intermediate consumption, IWF_k, and final consumption, FWF_k (where k denotes each category of plastic). Then, the total amount of plastic waste, from intermediary consumption, IW_i, and final consumption, FW_i, is calculated by the following formulas:

$$PD = PD_i = (ID_i + FD_i) \quad (1)$$

$$PO = PO_i = (PD_i + IM_i - EX_i) \quad (2)$$

$$IW = IW_i = (ID_i * IWF_j) \quad (3)$$

$$FW = FW_i = (FD_i * FWF_j) \quad (4)$$

$$PW = IW + FW = IW_i + FW_i \quad (5)$$

Regarding investigated data on production processes/norms, distribution, consumption, and recycling, the research surveyed 10 plastic factories, and 45 household-scale facilities in plastic recycling trade villages. Among the factories, there are five facilities producing plastics for intermediate demand (such as plastic film and planks) and five facilities producing plastic resins. Among the households, 30 facilities are producing plastics for intermediate demand and 15 facilities are producing plastics for final demand. All these factories and households are located in the North of Vietnam. Regarding experimental data on disposable plastics, the research sampled solid waste at Nam Son landfill, the biggest landfill in the North. The sampling and component analyzing method were followed six standard steps [25].

3 Results and discussion

3.1 PD and waste flows

Based on the IO data of 2007, 2012, and 2018, the PD per capita in Vietnam is 34.93, 50.67, and 82.68 kg, respectively. These values were still low when compared to the ones of Japan, Europe, the USA, and some other countries. From the supply side, the plastic industry (Sector 16) currently can produce only four of seven plastic material categories including PVC, PP, PET, and PS; among them, PVC occupies over 51% of total plastic material production capacity, and the industry needs to import more than 60% of total plastic material demand [3,27]. In 2018, the total amount of plastics produced in Vietnam (PO_{16}) was 10,287,589 tons, in which 3,589,339 tons were exported (EX_{16}) and 6,698,249 tons were distributed to 40 demanders, as shown in Figure 2. The country had to import 7,146,743 tons of plastic materials (including about 5,200,000 tons of virgin resin and 433,600 tons of recycled resin) and 1,503,143 tons of plastic products. Noticeably, the plastic industry contributed to all economic sectors of Vietnam, in which industrial sectors have higher PD than the agricultural, mining, and service sectors. The five highest demanders for plastics are *Electronic, electronic equipment* (S19), *Basic chemicals* (S15), *Transport equipment* (S21), *Food processing* (S8), and *Fashion manufacturing* (S9).

It should be noted that the IO table is simply a double-entry system of accounting for transactions between producers; there are assumptions in updating this static model, including (1) the inter-industry flows from i to j

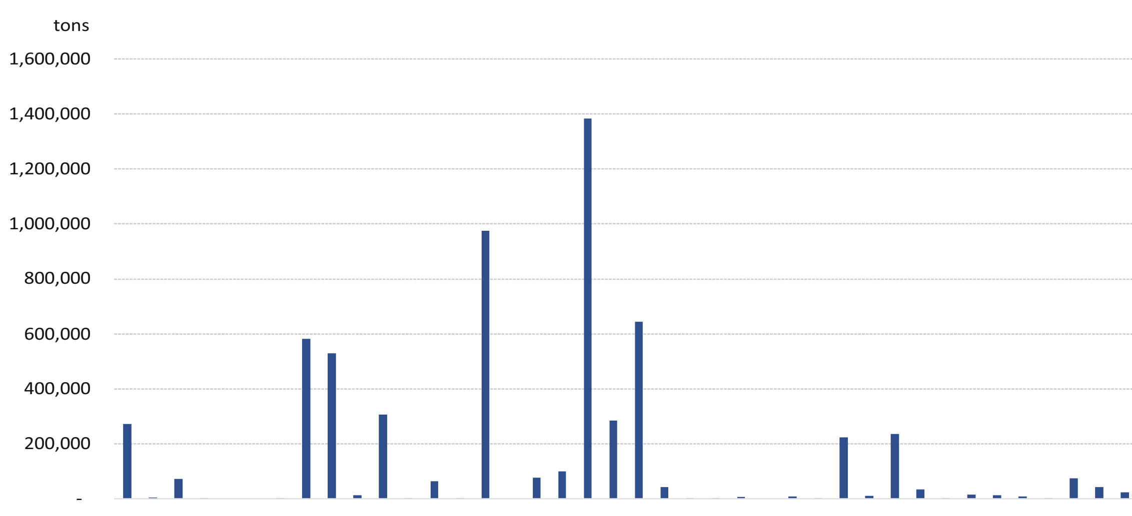

Figure 2: Plastic demand of 40 sectors in 2018. Note: ID and name of 40 sectors are presented in Table 1.

depend entirely and exclusively on the gross output of sector *j* for that same period [16]; economies of scale in production are ignored in the short run; production operates under constant returns to scale; and the Hawkins–Simon conditions are observed, meaning that to ensure all goods are producible, the sum of all the direct and indirect inputs of a commodity itself should not exceed the output of that commodity [26].

For the recycled resin, apart from import sources, domestic sources mainly come from recycled plastic craft villages, such as Minh Khai (Hung Yen) and Trieu Khuc (Ha Noi). Combining the national statistical data of solid waste collection and treatment and the investigated data at Nam Son landfill, the plastic waste flows in 2018 are estimated and presented in Figure 3.

As a result, over 60% of plastics after use were recycled, consisting of four parts: a part was collected by waste collection companies and then transported to plastic factories; a part was collected by scrap traders, gathered at plastic recycling trade villages and then transported to plastic factories afterward; a part was collected and arbitrarily recycled at plastic recycling trade villages; and a part was self-revolved by the producers. Nearly 40% of plastics after use left the cycle, consisting of three parts: a part was treated with domestic and medical solid waste; a part was disposed at landfills; and a part was uncontrollably discharged into the environment.

3.2 Plastic cycle and waste management solutions toward circular economy practice

3.2.1 Plastic cycle

To come up with better solutions for plastic waste management, we sketched out an overall picture of the plastic cycle based on the above results to quantify all primary and recycled material flows going in the stages of production, consumption, and disposal of plastics (Figure 4).

In a value chain of the plastic industry, the upstream includes petrochemical refineries and chemical plants, which transform fossil feedstock into plastic resins, and the downstream consists of manufacturers who convert plastic resins and recycled plastics into plastic products. In the plastic waste volume, the most visible waste but also easiest dispersion in the environment and finally into the sea is a single-use plastic package. For controlling the single-use plastic waste, we need to focus on both directions: upstream and downstream. For the upstream control, it is necessary to step by step to eliminate the production and consumption of plastic single-use products. For upstream activities, it needs to have the involvement of stakeholder groups: policymakers for stopping the production of single-use packaging products and replacing them with multiple-use ones or other materials and specialists in related

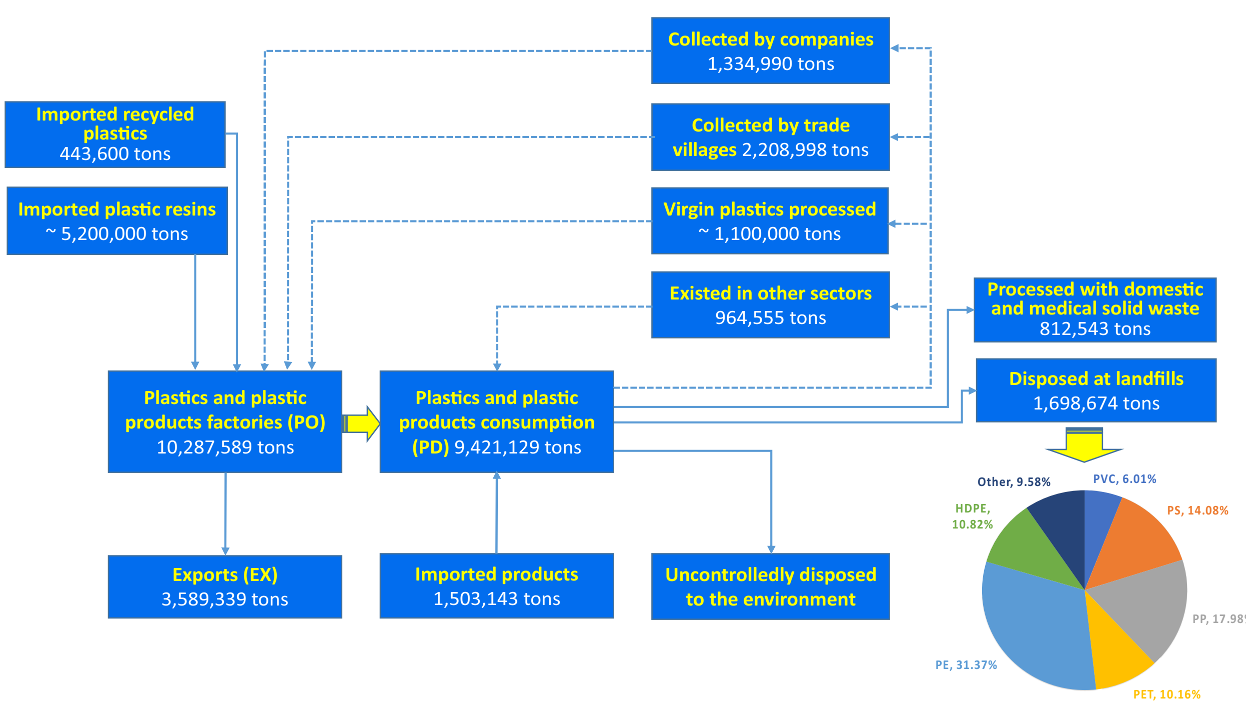

Figure 3: Plastic waste flows in 2018.

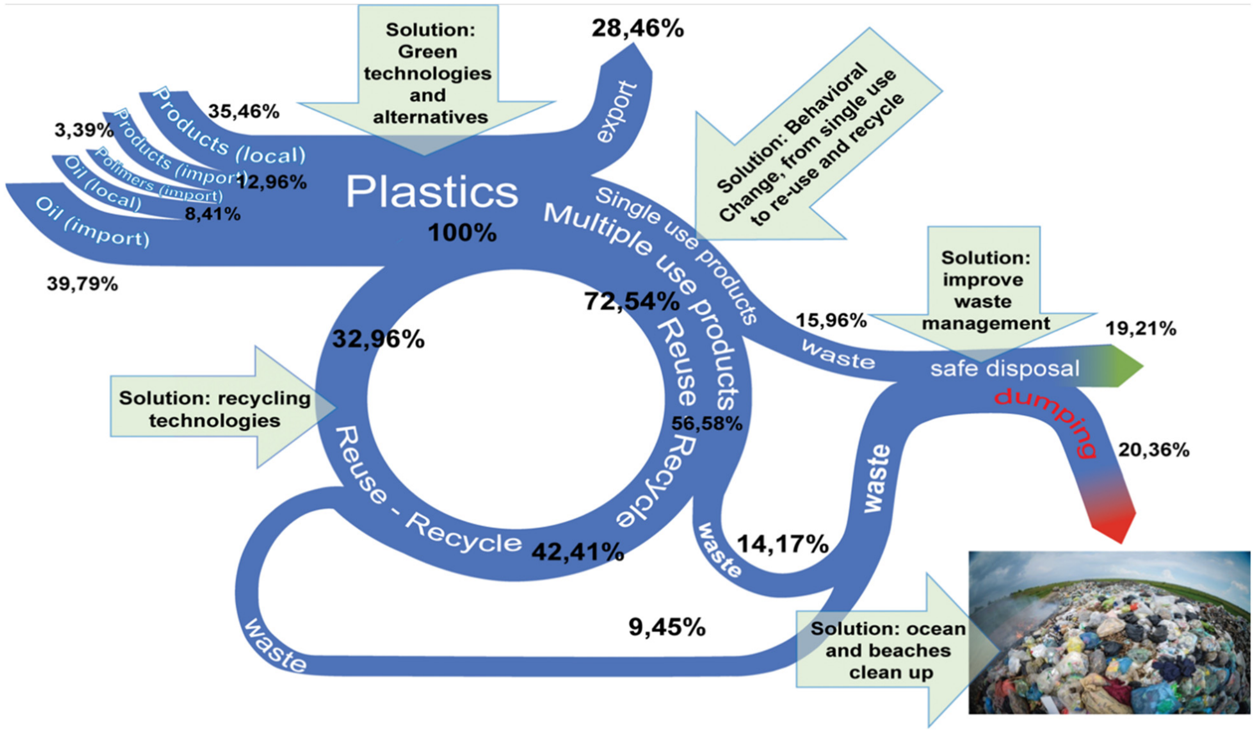

Figure 4: Plastic cycle 2018 with subconstruct toward circular economy practice.

issues for supporting management bodies and waste facilities' owners, for having different ways to get more benefits for their work related to plastic waste control (e.g., taxation, product standards, waste collection facilities, training, and education). For downstream activities, the priority should be put on feasible solutions and technologies to get higher efficiency in waste separation at sources as well as at waste collection and treatment centers. The main actors for this work should not be final users but mainly waste collectors and waste treatment facilities owners. As seen in the cycle, the single-use products (occupied 15.96% of total plastics) and indiscriminate waste in the environment (occupied 20.36% of total plastics) are the most challenging in waste management and the recycling and multiple-use products might be easier controlled.

3.2.2 Waste management solutions

It is noticeable that plastics are consumed by two groups with different characteristics: industries with major multiple-use plastics and households with both multiple-use and single-use plastic products. Although the industries use a large quantity of plastics, this group is governed for recycling materials to reduce production costs and the impact could be controlled and adjusted through legal regulations and manufacturers' benefits. In contrast, households often use disposable plastic products. Besides consumer's awareness, there is no compulsory regulation on the use and disposal of such products. Based on the IO data and the data investigated at 10 plastic facilities (including 5 facilities producing plastics for intermediate demand and 5 facilities producing plastic resins), the demand for HDPE, PE, PET, PP, PVC, PS, and others in 2018 is determined by converting X_{16j} in its corresponding physical units through producer's prices. The result is shown in Table 1.

The seven plastic types have distinctive features and environmental impacts throughout their life cycle [28]. Some plastics can be recycled multiple times and the scraps are often cycled back into the production process, so the rate of plastic waste discharged into the environment is usually low. Based on the data surveyed at the plastic factories and household-scale facilities, the waste generation rate of PP, PE, HDPE, PET, PVC, and PS products throughout their life cycle is defined as 43.03, 34.80, 32.91, 25.94, 29.11, and 28.48 kg per ton of product, respectively. The waste generation rate of PP is the highest because PP is inflammable. Then, the quantity of each plastic type discharged into the environment in 2018 was estimated as follows: PP, 2,823 thousand tons; PVC, 2,242 thousand tons; PE, 1,602 thousand tons; PET, 799 thousand tons; PS, 83.5 thousand tons;

Table 1: Sectoral demand of different plastic types in 2018

ID	Sector name	HDPE	PE	PET	PP	PS	PVC	Others
S1	Agriculture and its services	—	27,372	—	246,349	—	—	—
S2	Forestry and its services	—	—	—	5,930	—	—	—
S3	Fishery and aquaculture	—	36,111	—	36,111	—	—	—
S4	Hard coal and lignite	—	—	—	1,199	—	—	—
S5	Crude oil	—	—	—	—	—	—	—
S6	Natural gas or LPG	—	—	—	—	—	—	—
S7	Extractive	—	—	—	2,321	—	—	—
S8	Food processing	—	46,584	477,485	58,230	—	—	—
S9	Fashion manufacturing	—	450,563	10,601	26,504	42,406	—	—
S10	Wood products	—	—	—	13,532	—	—	—
S11	Paper and its service	—	138,126	–	168,820	—	—	—
S12	Coke	—	—	—	2,164	—	—	—
S13	Gasoline and lubricants	28,981	—	—	35,421	—	—	—
S14	Other oil mining	—	—	—	112	—	—	—
S15	Basic chemicals	976	8,785	—	937,035	—	29,282	—
S16	Plastics	798	485,726	119,085	527,081	5,117	515,325	8,220
S17	Building materials	3,840	—	—	3,840	—	66,047	3,072
S18	Metal production	—	5,036	—	65,463	—	30,214	0
S19	Electronic, electronic equipment	—	—	179,860	13,835	—	1,176,005	13,835
S20	Equipment and tool production	—	42,910	—	—	31,467	185,944	25,746
S21	Transport equipment	—	—	—	553,812	—	—	90,155
S22	Medical equipment	—	—	—	38,406	2,134	—	2,134
S23	Electricity and production and delivery	—	—	—	—	—	3,695	75
S24	Gas and services	—	—	—	—	—	27	—
S25	Water	—	—	—	—	—	6,423	338
S26	Sewerage and wastewater treatment services	—	—	—	—	—	—	—
S27	Solid waste collection and treatment services	—	9,144	—	481	—	—	—
S28	Other waste treatment	—	16	4	17	—	17	—
S29	Civil construction	—	—	—	—	—	218,813	4,466
S30	Repairing services	—	—	—	9,229	—	—	1,629
S31	Trading	2,376	142,560	11,880	76,032	2,376	—	2,376
S32	Transport	—	34,237	—	—	—	—	—
S33	Post services	—	253	—	—	—	—	—
S34	Hotels and catering	—	16,533	169	169	—	—	—
S35	Editing and communication services	—	13,927	—	—	—	—	—
S36	Financial intermediation and insurance services	—	507	—	—	—	9,634	—
S37	Real estate activities	—	4,065	—	—	—	—	—
S38	Other business activities	—	72,993	—	745	—	745	—
S39	Administrative and education	—	42,764	—	—	—	—	—
S40	Other community, social, personal services	—	24,249	—	—	—	—	—

Note: "—" is assumed to be negligible due to the small quantity.

HDPE, 36.9 thousand tons; and others, 152.05 thousand tons. A part of the above quantities went to landfills. Our experimental data at Nam Son landfill show that the disposal of plastics accounts for 1,698,674 tons, of which PE takes up a major proportion and PP is the next (Figure 3) – these two plastics are used to produce disposable packaging products, such as plastic bags and food packaging. They are disposed together with domestic solid waste and are difficult to be collected for recycling. In terms of waste management, solutions of replacing materials or raising taxes should be considered to apply for PE and PP.

Among segments of plastic products, the PET packaging segment is paid special attention. Compared to other plastic types, the collection rate of PET is the highest. Hence, the study focuses on PET and determines PET packaging flows (Figure 5).

Noticed from the figure, the collection rate of PET packaging was 84.63% in 2018. This means the uncollected rate of PET packaging was 15.37%, corresponding to 122,835 tons of PET discharged into the environment in 2018. This result is similar to IUCN's investigation (112,000 tons) [29]. Due to better reclaimable features

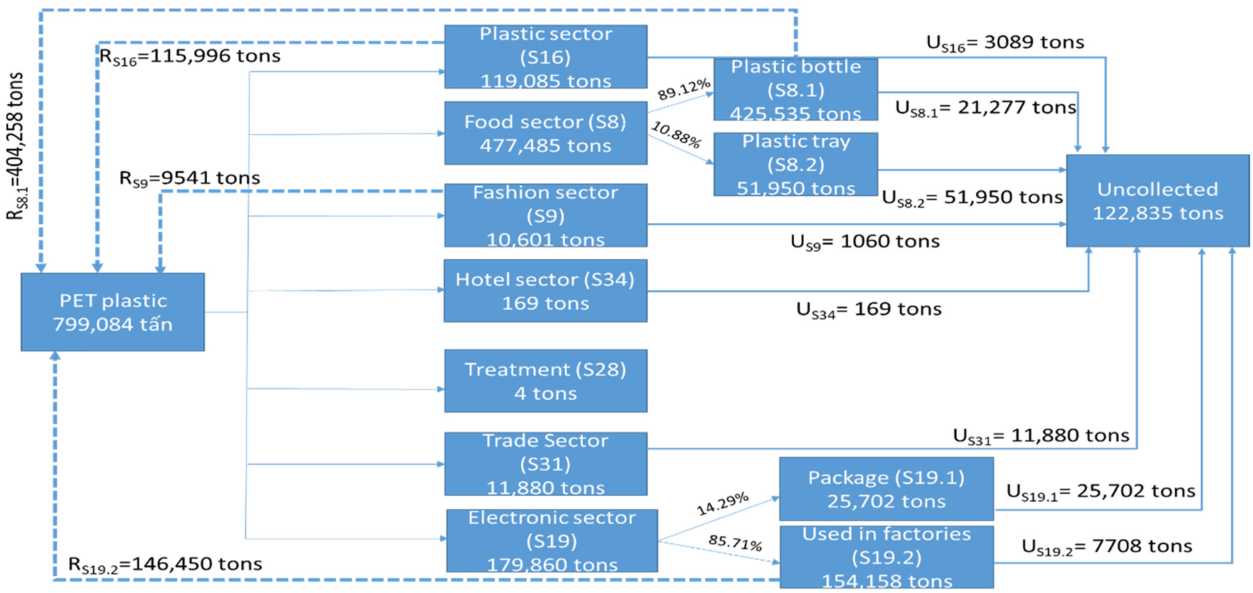

Figure 5: PET pakaging flows in 2018.

than other packaging materials, some PET packaging types are easily recoverable after use, such as drinking bottles in *Food processing* (S8) and PET packaging used to pack electronic components in *Electronic, electronic equipment* (S19), which is transferred and disposed of right away after the components have been assembled. Both the packaging types took up a high percentage of PET material, 53.25% in drinking bottles and 19.29% in electronics packaging. These PET packaging types have been collected both formally and informally, which also made their recovery rate higher than other types. In other plastic consumers, such as *Fashion manufacturing* (S9), *Trading* (S31), PET trays in *Food processing* (S8), and device packaging in *Electronic, electronic equipment* (S19), the recovery rate of PET is not very high because these PET packagings are disposed of directly by consumers and the collecting efficiency depends greatly on consumers' awareness. Moreover, PET trays that contain food are often disposed together with domestic waste. From the above, it is shown that the solution orientation of deploying extended producers' responsibility (EPR) is necessary to improve the collecting efficiency of this plastic packaging material. For the *plastic-consuming industries*, strategic solutions should contribute to pushing the EPR toward the circular economy practice in Vietnam and form market segments for the supply of recycled products. *For plastic-consuming households*, it needs to apply tax for using disposable or single-use products and promote communication media for changing consumption routines.

Pushing recovery of plastics after use should be prioritized since the plastic industry has a massive demand for scrap plastics. Depending on the quality requirements of the output products, scrap plastic could be used from 0% to 100%. The number of cycles for the recycling of plastics can be from 5 to 20 times. After each recycling, the properties of the plastics are changed and the quality of the plastics is reduced. Therefore, it is necessary to regulate the traceability of recycling times in the quality management of recycled plastic materials. Our other study on life cycle assessment of some plastic products showed that if a plastic product was produced from 100% scrap, its life cycle greenhouse gas emissions would be reduced by 32.21% compared to a product made from virgin materials [30]. All together contribute to reducing the import of scrap, which is a concerning issue currently.

4 Conclusion

This is the first study developing a plastic cycle in Vietnam that plays a data-driven base to orientate solutions toward reducing the rate of plastics disposed of or increasing the rate of plastics self-processed. Each stage of the cycle plays a distinctive role in improving the effectiveness of plastic waste management solutions including green technologies and alternatives; behavioral change, from single use to reuse and recycle; recycling technologies; and ocean and beach cleanup. Currently, the most challenge for waste management in Vietnam is to control single-use products and waste flows in the environment. Using 2018 IO data, the status of production, consumption, and disposal of plastics by industries and households are determined for 2018. Toward circular economic practice, the decision-making on waste management solutions needs to be data driven, accessible to material flows or consumer's targets, and impact all steps in the process: designing, processing, distributing, consuming, and recovering.

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Conflict of interest: The authors state no conflict of interest.

Data availability statement: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

[1] UNEP (United Nations Environment Program). Decoupling natural resource use and environmental impacts from economic growth. In: Fischer Kowalski M, Swilling M, Von Weizsäcker EU, Ren Y, Moriguchi Y, Crane W, et al. editors, A report of the working group on decoupling to the international resource panel. UNEP/Earthprint; 2011.
[2] OECD. Resource Productivity in the G8 and the OECD. A Report in the Framework of the Kobe 3R Action Plan; 2012. https://www.oecd.org/env/waste/resourceproductivityintheg8andtheoecd.htm>.
[3] Vietnam Plastic Association. Plastic Industry Report 2018; 2018 (in Vietnamese).
[4] Ministry of Industry and Trade. Decision No. 2992/QD-BCT on approving the development plan of Vietnam's plastic industry to 2020, vision to 2025; 2011.
[5] Government of Vietnam. Decree 122/2016/ND-CP on schedules of preferential import tariffs, compound tariff, and out-of quota import tariff; 2016.
[6] The People's Committee of Binh Duong. Decision No. 88/QD-UBND on guiding the collection and calculation of emission factors in Binh Duong province in the period of 2013 – 2020; 2014 (in Vietnamese).
[7] Thai NTK, Huong LTM. Evaluation of real situation of solid waste management at scrap recycling villages and proposing management solutions. J Sci Technol vivil Eng. 2011;5:114–20 (in Vietnamese).
[8] WWF (World Wide Fund For Nature). Survey on status of plastic waste in Vietnam; 2019 (in Vietnamese). http://d2ouvy59p0dg6k.cloudfront.net/downloads/tom_tat_ket_qua_khao_sat.pdf.
[9] SIWI (Stockholm International Water Institute). Analysis of plastic waste management from source to sea in Vu Gia – Thu Bon river Valley; 2019 (in Vietnamese). https://www.siwi.org/wp-content/uploads/2020/06/VGTB-Plastic Report_VN_FINAL-1.pdf.
[10] GA Circular. Accelerating the Circular Economy for Post-consumer PET bottles in Southeast Asia; 2019 (Last visit: May 2020). https://www.gacircular.com/full-circle/.
[11] Vietnam Prime Minister. Directive 33/CT-TTg on strengthening the management, reuse, recycling, treatment and minimisation of plastic waste; 2020.
[12] Kalmykova YM, Sadagopan M, Rosado L. Circular economy–From review of theories and practices to development of implementation tools. Resources Conserv Recycling. 2018;135:190–201. doi: 10.1016/j.resconrec.2017.10.034.
[13] World Economy Forum. Towards the Circular Economy: Accelerating the scale-up across global supply chain. Geneva, Switzerland; 2014. https://www.weforum.org/reports?utf8=%E2%9C%93&query=Towards+the+Circular+Economy%3A+Accelerating+the+scaleup+across+global+supply+chain.
[14] Leontief W. Quantitative input and output relations in the economic systems of the United States. Rev Econ Stat. 1936;18:105–25.
[15] Thomas VB. Input-output analysis in developing countries. New York: John Wiley and Sons LTM; 1985.
[16] Miller RE, Blair PD. Input-output analysis: foundations and extensions. New York: Cambridge University Press; 2009.
[17] Nakamura S, Nakajima K, Kondo Y, Nagasaka T. The waste input-output approach to materials flow analysis. J Ind Ecol. 2007;11(4):50–63. doi: 10.1162/jiec.2007.1290.
[18] Salemdeeb R, Al-Tabbaa A, Reynolds C. The UK waste input–output table: linking waste generation to the UK economy. Waste Manage Res. 2016;34(10):1089–94. doi: 10.1177/0734242X16658545.
[19] Nguyen TAT, Tran TC, Dinh BK. Analysis of waste flows using IO table. Vietnam J Sci Technol. 2018;56(2C):201–6. doi: 10.15625/2525-2518/56/2C/13049.
[20] Ruiz-Peñalver SM, Rodríguez M, Camacho JA. A waste generation input output analysis: The case of Spain. J Clean Prod. 2019;210:1475–82. doi: 10.1016/j.jclepro.2018.11.145.
[21] Yao Y, Chang Y, Masanet E. A hybrid life-cycle inventory for multi-crystalline silicon PV module manufacturing in China. Env Res Lett. 2014;9(11):11400. doi: 10.1088/1748-9326/9/11/114001.
[22] Crawford RH, Bontinck PA, Stephan A, Wiedmann T, Yu M. Hybrid life cycle inventory methods–a review. J Clean Prod. 2018;172:1273–88. doi: 10.1016/J.Jclepro.2017.10.176.
[23] Nakamura S, Kondo Y. Waste input-output analysis: concepts and application to industrial ecology. Tokyo: Springer Science + Business Media B.V.; 2009.
[24] Tsukui M, Kagawa S, Kondo Y. Measuring the waste footprint of cities in Japan: An interregional waste input–output analysis. J Econ Struct. 2015;4:18.
[25] ASTM D5231-92. Standard test method for determination of the composition of unprocessed municipal solid waste. West Conshohocken, PA: ASTM International; 2016.

[26] Hawkins D, Simon H. Note: some conditions of macroeconomic stability. Econometrica. 1949;17(3–4):245–8.
[27] Liang Y, Tan Q, Song Q, Li J. An analysis of the plastic waste trade and management in Asia. J Waste Manag. 2021;119:242–53.
[28] Schwarz AE, Ligthart TN, De Bizarro G, Wild PD, Vreugdenhil B, Van Harmelen T. Plastic recycling in a circular economy; determining environmental performance through an LCA matrix model approach. J Waste Manag. 2021;121:331–42.
[29] IUCN-EA-QUANTIS. National Guidance for plastic pollution hot spotting and shaping action, Country report Vietnam; 2020. https://plastichotspotting.lifecycleinitiative.org/wp-content/uploads/2020/12/Vietnam_Final-report_2020_10_22.pdf.
[30] Nguyen TAT, Ta TY. Comparison of life cycle impacts of some substitute products and approaches towards circular economy in the paper and plastic industries. Closing Workshop of the UK-REL Project "Circular Economy Knowledge Hub: Promoting Multi-Disciplinary Research, Capacity Building and Leadership". Hanoi, Vietnam; 2021 (in Vietnamese).