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An analysis of the plastic waste trade and management in Asia

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ABSTRACT

It is well known that Asia generates and receives large quantities of plastic waste. Through a detailed study of plastic waste generation and trade, the management and treatment of plastic waste in Asia were analyzed from the regional perspective. The amounts of plastic waste in municipal solid waste and in industrial solid waste were estimated to be 79 Mt and 42 Mt, respectively, in Asia. The overall treatment and recycling status in Asia are unsatisfactory. Asia imported 74% of the plastic waste in the world in 2016, and China (mainland) imported the most plastic waste until 2017, with 5.8 to 8.3 Mt. In 2017, about half the plastic waste imported by Asia came from other regions, and after subtracting the exported quantity, 98% of the plastic waste was left in Asia for treatment and disposal. The plastic waste imported by Asia declined about 72% in monetary value in 2018. There is still a large gap between the plastic waste quantity imported to Asia and that exported from Asia. China's ban of plastic waste imports caused import quantities to drop to 52 kt in 2018, simultaneously, exports from the largest exporting countries or regions such as Hong Kong (China), the USA, Japan, and Germany decreased. While Vietnam, Malaysia and some other Asian countries and regions saw significant increases in plastic waste imports from 2016 to 2018. Considering this situation, countries in Asia are starting to strictly limit plastic waste imports from other countries.

1. Introduction

Plastics, with their remarkable properties, have become a major commodity on a global scale, and are now present in almost all types of commercial products. Global production of resins and fibers increased from 2 Mt in 1950 to 380 Mt in 2015 (Geyer et al., 2017). However, the use of plastics has also brought adverse environmental impacts associated with their production and disposal. It was reported that the world generated 242 Mt of plastic waste in 2016 (Kaza and Yao, 2018). From 1950 to 2015, an estimated total of 6.30 billion tons of plastic waste was generated, with only 9% recycled, leaving more than 80% to accumulate in landfills or in the natural environment (Brooks et al., 2018). Plastic waste now makes up the majority of marine litter. Under ultraviolet light from the sun, plastic is degrading into plastic fragments or even "microplastics" that are almost impossible to recover and that are disrupting food chains and degrading natural habitats (NOAA, 2017).

Plastic waste has attracted great attention throughout the world (UN Environment Assembly; Secretariat of the Basel, Rotterdam and Stockholm Conventions); Research on plastic waste has focused primarily on recycling technologies (Al-Sabagh et al., 2016; Chen et al., 2019; Dhawan et al., 2019; Zhao et al., 2019) and the pollution it causes (Aryan et al., 2019; Sevigne-Itoiz et al., 2015). Various management and evaluation methods have been used in plastic waste management. Among them, marine microplastics and post-consumer plastic packing are an emerging plastic waste issue (Brouwer et al., 2018; Dahlbo et al., 2018; Duan et al., 2019). The various sources attributed to marine microplastics, and the status quo of microplastics pollution, were summarized in (Wang et al., 2018; Li et al., 2016; Bai et al., 2018), who together conducted an estimation and prediction of annual plastic waste input to the sea (Worm et al., 2017). Some studies have also focused on the plastic waste trade (He et al., 2018) and material flow. Stocks and flows of certain kinds of plastic in several countries or regions have been investigated (Ciacci et al., 2017; Van Eygen et al., 2017; Zhou et al., 2013). These types of

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studies have focused mainly on individual countries' trade or policy shifts.

Asia accounts for more than 50% of worldwide plastic production (PlasticsEurope, 2018), and about 74% of the exported plastic waste in the world has entered Asia in recent years (International trade Centre, 2019). However, the status of plastic waste management and recycling in Asia is not ideal; and some countries lack the basic recycling technology and facilities required. While public concern about plastic pollution is moving forward, the scientific understanding of this issue is still fragmented. Improving this understanding is vital to finding ways to reduce the generation of this waste, to better manage it and find a harmless treatment method for it.

This study investigated the plastic waste trade and management status in Asia and tried to discover the inadequacies in plastics management. First, the "bottom-up" method is used to estimate the plastic waste generation in typical countries of Asia and to provide basic data to further discuss the plastic waste trade and management. Plastic waste recycling status and management regulations in typical countries are summarized in this part. Next, the study focuses on plastic waste trade analysis including a description of the status of the plastic waste trade, and the plastic waste trade flow in typical Asian countries and regions, in 2017 and 2018. Meantime, plastic trade policies of typical countries are summarized. Finally, to understand the nature of the trade for some individual country or region in the plastic waste trade flow of Asia, two coefficients are introduced: R_j and D_j, representing the relationship between plastic waste trade and plastic waste generation.

2. Materials and methods

2.1. Data sources

The data for plastic production, trade, and recycling were taken from UN trade statistics (UN Comtrade Database, 2019), the trade map, the International Trade Centre (International Trade Centre, 2019), the Industrial Commodity Statistics Database, United Nations Statistics Division (Industrial Commodity Statistics Database, 2019), state environmental bureaus or statistical bureaus, reports from the Workshop 2018 of the Asian Network (2018) and national and state reports of the Sixth through Eighth Regional 3R Forums in Asia and the Pacific (2015); (2016;); (2018). Of all the plastic products (code 39) in the HS (International Convention for Harmonized Commodity Description and Coding System, Harmonized System), code 3915 refers to plastic waste, parings and scrap. Here plastic waste refers to the products belonging to code 3915, and the plastic products refer to the products belonging to code 39 (3915: includes the value and quantity of plastic trade in this study).

2.2. Plastic waste generation estimation

Some studies have focused on the plastic waste generation in one particular country or area, while for thorough research, plastic waste generation data for many different countries and regions are needed. Data availability is the biggest challenge in a study like this. There are two main methods of estimating plastic waste generation: "bottom-up" and "top-down" (Geyer et al., 2017). The bottom-up method uses solid waste generation data, typically given in kilograms per capita per day (Hoornweg et al., 2012). The "top-down" method uses plastic production data and their lifetime distributions. The production volume of plastics and the proportion of different types of plastics in various countries in Asia, however, are not available.

Consequently, the "bottom-up" method was used here to estimate the generation of plastic waste in Asian countries and regions. The plastic waste volume in Asian countries was estimated with the following formula (1–1).

$$W_j = S_{MSWj} * (r_{MSWj} + 2\%) + P_j * k_j * r_{ISWj} \quad (1\text{-}1)$$

where W_j is the total amount of plastic waste in a country or region j, $r_{MSW}j$ and r_{ISWj}refer to the proportions of plastic waste in municipal solid waste (MSW) and industrial solid waste (ISW), S_{MSWj} represents the MSW quantity of country or region j. P_j refers to population. MSW volumes, and the ratio of plastic waste in MSW, for various countries, have been reported in previous researches (see Table S1). For countries where no existing data were available, the average proportion of plastic in MSW was used. Some studies (Sasaki et al., 2018) have pay attention to the informal recycling system, for example, the rate of plastic recycled in Jakarta, Indonesia was determined to be 24%, through material flow analysis (Putri et al., 2018). In most countries, including China, the plastic waste in MSW is largely dependent on informal recycling for processing. To include the recycled plastic waste from MSW, the ratio of plastic waste in MSW was therefore adjusted upward by 2%.

As for ISW generation and the ratio of plastic waste in ISW, relatively little data were available. Thus, the average industrial waste generation k_j (tons/capita/year) was used, and k_j was based on GDP per capita. Similar estimation methods have been used in other reports (Kaza et al., 2018). The following formulas were used here:

(1) k_j = 2.03, GDP per capita $\geq$ 30000 dollars (based on generation data from Japan, Ministry of the Environment, Japan. 2018)
(2) (2)k_j = 1.66, 10000 < GDP per capita less than 30000 dollars (based on generation data from Korea, Ministry of Environment, the Republic of Korea. Environmental Statistics Yearbook, 2017)
(3) k_j = 1.03, 8000 < GDP per capita less than 10000 dollars (based on generation data from China, Ministry of Ecology and Environment of the People's Republic of China, 2019)
(4) k_j = 0.54, GDP per capita $\leq$ 8000 dollars (based on generation data from Thailand, Wichai-utcha and Chavalparit, 2019).

In consideration of data availability, plastic waste quantities of Asian countries in 2016 were estimated using formula (1–1). It is assumed that plastic waste generated by per person per year is comparatively stable in the following two years (2017 and 2018) and the total plastic waste quantities increase with population. Based on this, plastic waste quantities of Asian countries in 2017 and 2018 were calculated. Further, compared with the amount of solid waste generated per capita, the total amount of solid waste generated by one country or region is an official statistic and has higher accuracy. In some countries or regions, where plastic production or waste data are available, comparison methods can be used to evaluate the reliability of estimation results. The top-down, therefore, was used comparison; these data can be found in the supplementary material (Equation S1 and Tables S2-S3).

2.3. Plastic waste trade analysis

The plastic waste trade analysis included three steps: first, the plastic waste trade was described here with major import and export data; secondly, a plastic waste trade flow mode for typical Asian countries and regions was built, with plastic waste input divided into imports from outside Asia and imports from within Asia (only typical Asian countries and regions with import quantities over 1% were included). Output plastic waste included three types: exports to other regions in Asia, exports to regions outside

Asia and waste kept in the originating countries or regions for treatment. The trade value was used to demonstrate the flow of plastic waste. In defining input, "Plastic waste generation" was here to balance input and output; it is not equal to the total waste generation value. The analysis years were 2017 and 2018, when China's ban on imported plastic waste took effect.

Finally, in order to understand the characteristics of the trade for individual countries or regions, and the roles different countries or regions played in the plastic waste trade flow of Asia, two coefficients, R_j and $D_j$were used (Equations (1)-(2) and 1–3, Fig. 1).

$$R_j = \frac{Q_{ej}}{W_j} \tag{1-2}$$

$$D_j = \frac{Q_{ej}}{Q_{Ij}} \tag{1-3}$$

In traditional international trade statistics, the foreign trade coefficient is the import or export compared to GDP, and reflects the degree of dependence of a country on international trade. Here it is used to describe the trade in plastic waste, and the trade coefficient R_j is the ratio of plastic waste exported, to plastic waste generation within the country (or region) j. It reflects the level of plastic waste exported and the dependence of one country on plastic waste treatment in other countries. Contrary to traditional implications, the higher the export trade coefficient, the higher the dependence of one country on another country's plastic waste treatment. In addition, $D_j$reflects the export and import exchange coefficient, a newly introduced concept. Q_e and Q_I are the export and import quantities of one country, respectively, and j is the country being estimated. Based on the availability of data and the country's influence on the total trade, only countries or regions with plastic waste generation over 1Mt/year are discussed here.

Assumptions and judgments:

$R_j > R_{average}$
- $D_j > 2$, country(j) is recognized as a main *Exporter*
- $0.5 \leqslant D_j \leqslant 2$, country(j) is recognized as a *Transferer*
- $D_j < 0.5$, country(j) is recognized as an *Importer*

$R_j < R_{average}$
- $D_j < 0.5$, country(j) is recognized as an *Importer*
- Else, are not discussed

The assumption was made that, in general, the export ratios of plastic waste generated by the countries or regions themselves are at the same level. When $R_j$is higher than the average R of all countries in Asia, it can be concluded that country (j) has a relatively strong influence on plastic waste exports: i.e., country (j) exports more plastic waste, whether generated internally or imported from other regions. D_j was also compared to other countries: ifD_j exceeded 2, it indicated that exports far exceeded imports, and country (j) was recognized as a main *Exporter*; whenD_j was between 0.5 and 2, it was assumed that country (j) exports not only the plastic waste it generates itself but also that imported from other regions, and (j) is recognized as a *Transferer*; when D_j was lower than 0.5 (import quantity is more than double export quantity), no matter the relative value of R_j, it was recognized as a main *Importer*. Other cases, such as when R_j is lower than the average, and D_j is more than 0.5, it can be seen that such countries have only small effects on the trade, and they were ignored for the purposes of this study. The target analytical years were 2016–2018, and during this time, the roles of different countries or regions may have experienced some changes.

3. Results and discussion

3.1. Plastic waste generation and recycling in Asia

3.1.1. Estimation of plastic waste generation

Asia has become one of the most important plastic production and consumption areas. From 2013 to 2015, plastic production in Asia increased from 114 to 131 Mt (Liu., 2018). The total Asian production quantity of major plastic resins was 82 Mt, of which China's share was 44.79 Mt. The next largest production countries were India and Korea with 14.17 and 13.68 Mt, respectively. Although India's plastic consumption, at 12 kg/ capita/year, is still only one tenth that of the US, and less than a third of China's (Indian Council for Research on International Economic Relations, 2018). Nevertheless, the projected high growth rates of GDP and continuing rapid urbanization suggest that India's plastic consumption and plastic waste in the future is likely to rise sharply. The main usage of plastics is in the form of packaging bags, fluid containers, clothing, toys, household applications, industrial products, engineering applications, building materials, etc. Plastics used in packaging offers significant potential for growth, leading to an increase in the demand for plastics. It is known that about 50–

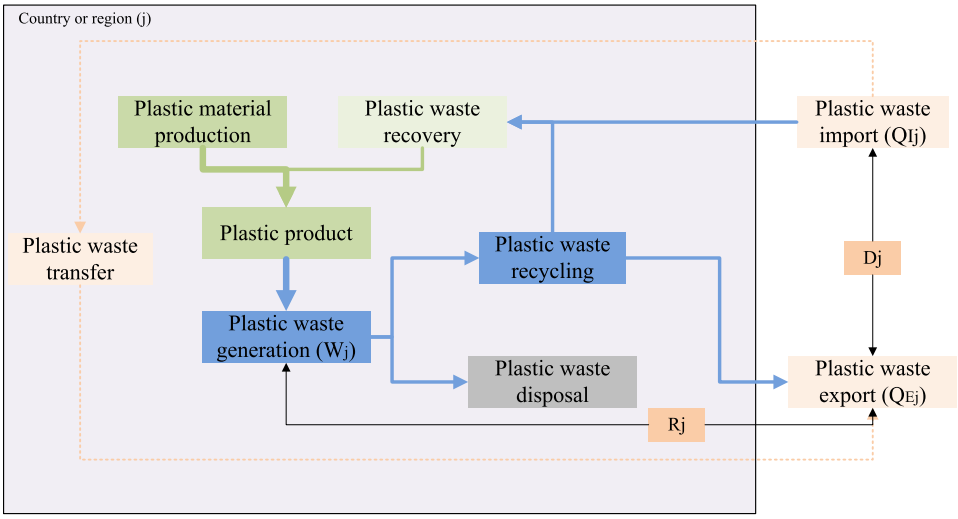


Fig. 1. Relationship between D_j and R_j (dashed lines connecting plastic waste transfers means the activity may occur in some countries or regions).

Table 1
Statistics on waste plastic generation in Asian countries (Mt).

Country	MSW (2016)	ISW (2016)	Plastic ratio in MSW (%)	Plastic waste in MSW	Plastic waste in ISW	Total plastic waste (2016)	Total plastic waste (2017)	Total plastic waste (2018)
China	203.6	1480.0	13	30.54	18.5	49.04	49.19	49.71
India	71.2	715.1	10	8.54	8.9	17.48	17.58	17.66
Japan	43.2	392.8	12	6.04	4.9	10.95	11.07	11.19
Turkey	33.8	85.4	13*	5.06	1.1	6.13	6.21	6.28
Thailand	27.5	37.2	17.6	5.38	0.5	5.85	5.88	5.96
Pakistan	30.2	61.8	13*	4.52	0.8	5.30	5.40	5.51
Korea, Rep.	19.6	132.0	12	2.75	1.6	4.40	4.39	4.38
Vietnam	22.0	51.1	10	2.64	0.6	3.28	3.29	3.30
Iran, Islamic Rep	17.7	43.3	13*	2.65	0.5	3.20	3.19	3.24
Saudi Arabia	15.3	53.6	13*	2.30	0.7	2.97	3.05	3.11
Indonesia	6.1	141.0	14	0.98	1.8	2.74	2.95	3.01
Philippine	14.6	55.8	10.6	1.84	0.7	2.53	2.58	2.61
Malaysia	13.4	33.5	13.2	2.04	0.4	2.45	2.60	2.65
Singapore	7.7	11.4	11.6	1.05	0.1	1.19	1.22	1.24
Israel	5.4	17.3	13*	0.80	0.2	1.02	1.02	1.03
Yemen, Rep.	4.8	14.9	13*	0.73	0.2	0.91	0.92	0.93
Sri Lanka	2.6	11.4	13*	0.39	0.1	0.54	0.55	0.56
Mongolia	2.9	1.6	13*	0.44	0.0	0.46	0.46	0.46
Tajikistan	1.9	4.7	13*	0.29	0.1	0.35	0.36	0.36
Qatar	1.2	5.2	13*	0.17	0.1	0.24	0.24	0.25
Turkmenistan	0.5	6.1	13*	0.08	0.1	0.16	0.16	0.16
Brunei Darussalum	0.2	0.9	13*	0.04	0.0	0.05	0.05	0.05

* The number is the average of the known data.

60% of plastic consumption is converted into waste (Ministry of Environment, Forests, Government of India, 2015).

Accompanied by the increasing consumption of plastic products in recent years, plastic waste generation should not be ignored. Using these ratios of plastic waste in municipal solid waste (MSW) and industrial solid waste generation, we estimated the plastic waste amounts in Asian countries in 2016 (detailed information is in Table S1). The results are shown in Table 1. Countries with MSW of less than 0.2 Mt are not counted here. We know that the plastic waste rate in MSW ranges from 8% to 18%, based on available data, and that this estimated plastic waste in MSW accounts for the largest share of the total waste. The total amount of plastic waste in MSW is about 79 Mt, and plastic waste in ISW is 42 Mt within these countries. China produced the highest amount of plastic waste: 49 Mt per year. India, Japan, Turkey, Thailand, Pakistan and Korea follow, each producing more than 4 Mt per year. In Vietnam, plastic consumption has increased rapidly, from 3.8 kg/capita/year in 1990 to 41 kg /capita/year in 2015 (Vietnam Environment Administration MoNRE, 2018), and it estimated 3.28 Mt plastic waste generated in 2016. Japan's case shows that, of the plastic waste in MSW, 78% is containers and packaging, while in industrial waste, electrical products and machinery make up 33% (MINAMIKAWA, 2018).

The estimation method used in this study is based on the proportions of plastic waste in different waste streams, and the proportion can affect the plastic waste quantity to some extent. To figure out the impact of plastic ratio on the estimation results, global sensitivity analysis was used. Because of the lack of plastic waste ratio data in some countries, the average value of 13% was used to estimate the plastic waste in MSW. When a ratio changed from a relatively low proportion to a high level, the effect on the final result was tested. When the share of plastic waste ranges from 10% to 16%, the plastic waste generation in Asia changes from 118 Mt to 125 Mt, and the relative error are 2% and 3%. In the overall trade role analysis, the change in the amount of plastic waste amount does not affect the roles of those countries.

To estimate the plastic waste generation in Asia, two methods can be used, as mentioned in Section 2.1, and because of the lack of data, the bottom-up method was used in this study. To test the reliability of the results, the plastic waste generation in China was then calculated by the top-down method; these data can be found in the supplementary material (Equation S1 and Tables S2-S3). In some countries or regions, where plastic waste quantities were available, comparison of estimation and statistical data was performed. The estimation results are shown in Table 2: the plastic waste generation in China estimated by the two methods are very close, with about 0.7% relative error. From the bottom-up method, packaging waste makes up the largest proportion (67%, Table S4). Then a comparation between the statistical data with the estimation results in countries of Korea, Japan, Singapore and Thailand shows that the estimated data are larger than the statistical data, the difference may be caused by a higher ratio of plastic waste in solid waste. The relative errors are in the range of 0.7% to 50%.

3.1.2. Recycling and management

Some Asian countries have established regulations for better management of plastic waste, (Table 3) (Ministry of the Environment, Japan, 2018; Ministry of Environment, Forest and Climate Change, Government of India, 2018; Workshop, 2018 of the Asian Network, 2018; Eighth Regional 3R Forum in Asia and the Pacific, 2018; Wichai-utcha and Chavalparit, 2019). In Japan, for example, the Container and Packaging Waste Recycling Law issued in 1995 was extended to apply to municipal plastic waste, in 2000. Also,

Table 2
Comparison between different methods (Mt).

Country	Statistical data (or estimation using top-down method)	Estimation using bottom-up	Relative error
China	49.4 (estimation using top-down method)	49.0	0.7%
Korea	2.7[1]	2.8[2]	3.7%
Japan	8.9[3]	11.2	25.7%
Singapore	0.8[4]	1.2	50.0%
Thailand	4.1[5]	5.8	41.5%

[1] Plastic waste in MSW, Environmental Statistics Yearbook
[2] Plastic waste in MSW
[3] The Japan plastics Industry Federation, 2018
[4] Waste Statistics and Overall Recycling Data, National Environment Agency, Singapore Government
[5] Bureecam et al., 2018

Table 3
Summary of policies on plastic waste management and imports in Asia.

Country	Plastic waste imports	Related regulations	Content
China	Forbidden	"Catalog of Solid Waste that Can Be Used as Raw Materials under Import Restrictions" "Catalog of Solid Waste Prohibited from Importation"	China has included 24 types of solid waste in four categories, including plastic waste from domestic sources (8 varieties), in the"Catalog of Solid Waste Prohibited from Importation" from the "Catalog of Solid Waste that Can Be Used as Raw Materials under Import Restrictions"
	Management	Administrative Measures for the Recovery of Renewable Resources (2007)	For the purposes of promoting the recovery of renewable resources (including plastic waste), saving resources, and protecting the environment.
Vietnam	Restricted	Law of Environment (2014) *Notice No. 27 of Prime Minister (2018) **Decision No. 73/2014 ***Circular No. 08/2018 / TT-BTNMT and Circular No. 09/2018 / TT-BTNMT	Vietnam allows the import of waste that meets environmental standards, and lists 36 types of waste (including vinyl polymer (PE) plastic waste) *Enhanced management of imported scrap, including scrap plastic **List of scrap accepted for import (including plastic scrap) ***Approved national technical regulations on scrap imports.
	Management	Decision No. 582 / QĐ-TTg of the Prime Minister (2013)	Approved the Scheme up to 2020 on enhancing the control of environmental pollution caused by plastic bags
Lao PDR	Restricted	"Environmental Protection Law" (Revised in 2013)	Organizations with hazardous waste or other waste import licenses are required to comply with the Basel convention conditions and regulations, and receivers providing treatment, reuse, recovery and destruction must have environmental compliance certificates (ECC), etc.
Malaysia	Restricted	Custom (Prohibition of Import) Order 2017	The import of plastic waste under HS Code 3915 is controlled under the Customs (Prohibition of Import) Order 2017. The import method requires an approval permit (AP) from the DNSWM.
Thailand	Forbidden	Department of Industry "Ban on the import of electronic and plastic waste "	Deferring on E-Waste and plastic scrap (dated 22 Jun 2018) Thailand plans to ban imported plastic scrap within 2 years. The quota for each year will be defined by Work.
	Management	National 3R strategy	Set the goal for plastic waste management: to recycle 60 percent of plastic waste by the end of 2021
Indonesia	Forbidden/Allowed	Regulation of the Minister of Trade of the Republic of Indonesia Number 31/M−Dag/Per/5/2016	Trade Ministry revision for Importation of Non-Hazardous Waste regulation: No more importation of plastic scrap. Indonesia will only receive plastic waste in flake, chip or pellet forms. HS Code for other types (mixed plastic) in the regulation will be deleted
	Management	Ministerial Regulation on Plastic Bag Reduction 10-Year Roadmap of EPR implementation for reducing plastic packaging waste (draft)	Reducing plastic bag waste by implementing plastic shopping bag fee at modern retail stores. Promoting and implementing EPR to reduce plastic packaging waste.
Cambodia	Forbidden	Solid Waste Management Sub-decree (1999)	Import of wastes/HW is strictly prohibited.
	Management	Sub-decree on Solid Waste Management (2017)	Reduce import, production, distribution and consumption of plastic bags
Philippines	Allowed	Republic Act 9003 - Ecological Solid Wastes Management Act of 2000	Imports for recycling are permitted; for disposal, prohibited. The Department of the Environment prohibits the import of mixed plastics but allows the import of relatively simple plastic waste. Enterprises do not need a license but are required to have an environmental protection certificate.
	Management	Ecological Solid Waste Management Act (2001)	Plastic waste is classified as recyclable material if readily combustible.
Singapore	Allowed	Environmental Protection and Management Act	Imports of wastes that can be used as raw materials are allowed.
	Management	The Prevention of Pollution of the Sea (Amendment) Act 2017	Prohibits the discharge into the sea of all plastics.
Japan	Allowed	Law for the Control of Export, Import and Other Specified Hazardous Wastes and Other Wastes (2018)	Any materials considered recyclable.
	Management	Recycling of Containers and Packaging (2000)	Glass bottles, metal cans, paper containers and packages, plastic bottles; plastic containers and packages excluding pet bottle containers
Korea, Republic of	Allowed	Waste Management Law	Recyclable materials only
India	Forbidden	*Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016.	*No import of hazardous and other wastes specified in Schedule VI (solid plastic waste included) shall be permitted. Scrap plastic of non-halogenated polymers and co-polymers, including but not limited to polypropylene, polyethylene terephthalate, etc.
	Management	Plastic Waste Management Rules (2016) Plastic Waste Management (Amendment) Rules (2018)	Provides a regulatory framework for management of plastic waste generated in the country.

some regulations, such as the Prevention of Pollution of the Sea Act in Singapore, mention protecting the sea from plastic waste pollution. In some countries, such as in Myanmar and Vietnam, however, there is still no specific policy/regulation or plan for plastic waste. Indonesia and Myanmar also lack appropriate technology for plastic waste stream management, although Malaysia is at the design stage of an EPR-based policy and regulatory regime. In Asia, even with current regulations, the effective management and recycling of plastic waste still has a long way to go. Although in some countries the collection rates are respectable, the industry is mainly dependent on the informal sector, and the recycling process consequently presents huge environmental risks.

In Asian countries and regions, not only the plastic waste generated domestically but also the imported waste faces great chal-

lenges in the solid waste treatment and recycling system. Imported waste plastics are generally mixed up with a certain proportion of solid waste, containing MSW and other kinds of imported waste: e.g., paper, batteries, and metal. When imported plastic waste is processed, large amounts of process waste are generated. In China, there were over 2100 renewable resources recycling enterprises using imported waste as raw material in 2015, of which 1266 were waste plastic processing enterprises. Among those, 64% were small and medium-sized enterprises, most of them performing simple disassembly and clumsy processing techniques, and the overall level of technology and equipment is not high.

In 2017, 380 Mt of plastic waste was generated globally and about 70 Mt was recycled— a recycling rate of 18% (Geyer, 2020). Asia generated over 121 Mt of plastic waste in 2016 and imported over 11.4 Mt. The limited information that is available on the amounts of plastic waste that is either collected, recovered or recycled in the Asian countries is gathered in table 4 (Bureecam et al., 2018; Satapathy, 2017; Ministry of Commerce of the people's republic of China, 2018; Ministry of Environment the Republic of Korea, 2017; Ministry of the Environment, Japan, ,2018; National Environment Agency, Singapore Government, Waste Type Waste Statistics and Recycling Rate for, 2016; National Environment Agency, Singapore Government, 2018). For a few developed countries, the recycling of plastic waste has a better outlook. In Japan, the plastic waste generation was 8.91 Mt in 2018, and 7.5 Mt was recycled—an 84% effective utilization rate (The Japan plastics Industry Federation, 2018). That effective utilization rate includes 23% for material recycling, 4% for chemical recycling and 56% for heat recovery (energy recovery). According to the Korea Environmental Statistics Yearbook (Ministry of Environment the Republic of Korea, 2017), Korea separately collected 1.1 Mt of plastic waste from MSW in 2016—a collection rate of 41%.

In China, the collection rate is about 33% of the plastic waste, including the imports and subtracting the exported plastic waste. In recent years, the collection weight of plastic waste decreased from over 18 Mt to 17 Mt. In India, the informal sector and households play a vital role in recovering consumer waste; together they collected 6.5–8.5 Mt of plastic waste, about 50–80% of the plastic produced there (Nandy et al., 2015). In Thailand, it is estimated that 4.1 Mt of plastic waste was generated in 2013; 3.6 Mt was collected and transported to disposal sites by the government, and 0.8 Mt was recycled by the government or independent merchandisers. Plastic waste not collected, however, came to about 0.5 Mt (Bureecam et al., 2018).

In other countries, including the Philippines, Pakistan, etc., the collection rates are far below 50%. Moreover, in some countries there is a lack of technology or capacity for plastic waste treatment, a deficiency that will cause more severe pollution and harm to the environment and human health. In Vietnam, the amount of plastic waste and plastic bags disposed of is approximately 2.5 Mt/year, and the recycling technologies there are obsolete—mainly at the household scale, in craft villages. In Indonesia only a few major cities have resource recovery facilities. In Lao PDR (Eighth Regional 3R Forum in Asia and the Pacific, 2018), there is still no biological treatment or formal recycling of solid waste, and the recycling rate is estimated at 10%. There are only 7 factories for plastic waste recycling in the entire country.

3.2. Management of the plastic waste trade

3.2.1. Plastic waste trade policies and impact

Along the tremendous production of plastics and generation of plastic waste, Asian countries have also become a dumping ground for plastic waste from the rest of the world. Hence, in addition to strengthening the management and treatment ability of the Asian countries themselves, the control of plastic waste imported from other regions has attracted great attention, and countries are attempting to address the issue. The Basel convention is playing a leading role in curbing the plastic waste flood and promoting the establishment of an important international mechanism to curb marine waste and plastic waste pollution. At the Eleventh meeting of the Open-ended Working Group of the Basel Convention (OEWG.11) (Basel convention, 2018), a proposal calling for controls on waste from plastics and mixed plastic materials was submitted as an amendment to the Basel convention. It is said that by explicitly including plastic waste in the Basel convention, these flows can be controlled and poor plastic waste management avoided.

Policies on plastic waste imports in Asian countries vary (Table 3). Japan, Korea, the Philippines and Singapore allow imports of plastic waste, which can be treated as recyclable materials under a conditional permit system. Some countries have also developed a number of management measures to regulate the imports. The Philippines, for example, allows the import of relatively simple plastic waste. In Lao PRD, Malaysia and Indonesia, applicants for import licenses or approval permits (APs) for plastic waste are required to demonstrate that they will comply with the Basel convention conditions and regulations.

Asia's share of the world imports of plastic waste was about 74% in 2016, with over 11 Mt. China (mainland), Hong Kong (China), Malaysia, Taiwan (China), and India are the top 5 importers of plastic waste in Asia (Table S5). China (mainland) imported the most plastic waste in the past five years; its proportion was 52% of the world imports in 2013. And when Taiwan and Hong Kong are added in, the ratio can be as large as 70%, although there is evidence that even as the import amount decreases, the ratio will still be high; it was 59% in 2017. Moreover, the imported quantity has remained at the level of 5.8 Mt to 8.3 Mt (mainland) in recent

Table 4
Plastic waste trade, generation and collection in Asia (2016, kt).

Country	Generation	Import	Export	Total	Gross weight of recovered plastics
China	49,043	7,347	30	56,360	18,780#
India	17,481	167	3	17,645	6,500–8,500#
Japan	10,954	2	1,527	9,430	7,500*
Thailand	5,845	69	306	5,609	766#
Korea	4,397	1	209	4,190	1,080#
Vietnam	3,281	102	276	3,106	–
Indonesia	2,738	172	204	2,706	–
Malaysia	2,454	288	164	2,579	–
Philippines	2,534	5	136	2,403	–
Singapore	1,189	3	75	1,117	60

- means unknown
collected weight
* recycled weight-data of 2018.
recycled weight

years, far exceeding other major importers in the world, including the Netherlands, the USA, Belgium, and others (Figure S1), whose proportions are quite small (less than 3.8%).

The huge import quantity of plastic waste has brought great environmental pressure to Asia, especially China. Since 2017, China gradually implemented the ban on imports of plastic waste, remarkable effects have been achieved: the import quantity was reduced from over 7 Mt to 5.8 Mt in 2017, and then dropped even more sharply, to 52 kt in 2018. The same tendency has shown up in Hong Kong (China), where the quantity dropped from over 2.8 Mt to 0.6 Mt in 2018. Until 2018, China has comprehensively banned the entry of 24 categories of solid waste, including plastic waste.

However, Malaysia has seen double and triple increases in 2017 and 2018 import amounts, compared to 2016. And from 2016 to 2017, Vietnam saw significant increases in plastic waste imports (350% in monetary value). Further, Taiwan (China), Indonesia, and Thailand increased their quantities by 110%, 150% and 260%, respectively, in 2018. It is worth noting that recycling enterprises are planning for the relocation of plants to the Southeast Asian region, where they are very likely to have adverse impacts on the local environment, especially for countries lacking the latest treatment technologies. And yet some countries have responded to the increased demand for plastic waste imports, especially since the import restrictions in China.

In 2018, Malaysia adjusted its policies to strengthen management of the imported plastic waste industry to avoid further imbalance of domestic plastic pollution. Vietnam, Thailand, Indonesia and other countries have also strengthened the management of plastic waste imports; some plastic waste, that can cause serious environmental pollution and cannot be handled domestically, will be banned from entering. Thailand plans to undertake capacity building for customs and other relevant officials to comply with the Basel Convention and to enact a ban on plastic scraps and used tires, in the future. And in the Trade Ministry of Indonesia, revisions to the Importation of Non-Hazardous Waste regulation state that it will only receive plastic waste in flake, chip or pellet forms, and mixed plastic will be prohibited entirely. In March 2019, India made two amendments to the Hazardous Waste (Management& Transboundary Movement) Rules, 2016, to impose a total ban on the import of plastic waste in all regions of India, including special economic zones and export-oriented areas (Ministry of Environment, Forest and Climate Change, 2019).

The logistic model was used to fit and analyze the data of plastic waste imported by Asia from 2001 to 2016 (Fig. 2). It can be found that the plastic waste import tends to be stable since 2013, in that time Chinese Customs launched a 10-month "Green Fence". Without the adjustment of trade policies from 2017, the predicted plastic waste import is 12.4 Mt in 2017. Compared with imported quantities in 2017, it has reduced about 2.9 Mt plastic waste import. According to the analysis in section 3.2.2, about 50% of the plastic waste was imported from outside Asia, it can be found that the implication of trade policies adjustment has prevented 1.4 million tons of waste plastic from flowing into Asia. In 2018 and 2019, the data has increased to 4.2 and 4.6 with the cumulative quantity of 10.2 Mt. The effects of Asia's import restrictions on global trade and domestic markets are already emerging.

As for plastic waste exports, Hong Kong (China) was the largest exporters in the world until 2017, followed by the USA, Japan, and Germany (Figure S2), while after the Chinese ban on the import of plastic waste, its export amount decreased, as did its import amount, from over 2.8 Mt to 288 kt per year. A study by He et al. (2018) showed a relatively strong positive correlation between the revenue of plastic waste flowing from the USA to Hong Kong (China) and then on to mainland China, suggesting that Hong Kong may play a transition role for this waste. With tightening Chinese customs regulations, plastic waste from other countries can no longer be exported to Hong Kong (China). Other countries like the USA, Japan, and Germany have also seen export decreases. Asia's share of world exports was about 37% in 2013 (Table S6) and it has maintained about a 40–43% level in recent years (monetary value). The top 5 exporters in Asia are Hong Kong (China), Japan, Thailand, Vietnam and Korea; they make up over 72% of the total exports in Asia. Before 2017, exports from Hong Kong (China) and Japan remained steadily above 1400 kt, Thailand about 300 kt, and Korea about 200 kt.

3.2.2. The plastic waste trade analysis in Asia

Based on the import data of Asian countries and regions, the main exporters to typical countries and regions in Asia are shown in Fig. 3. Hong Kong (China), Japan, and the USA, with export quan-

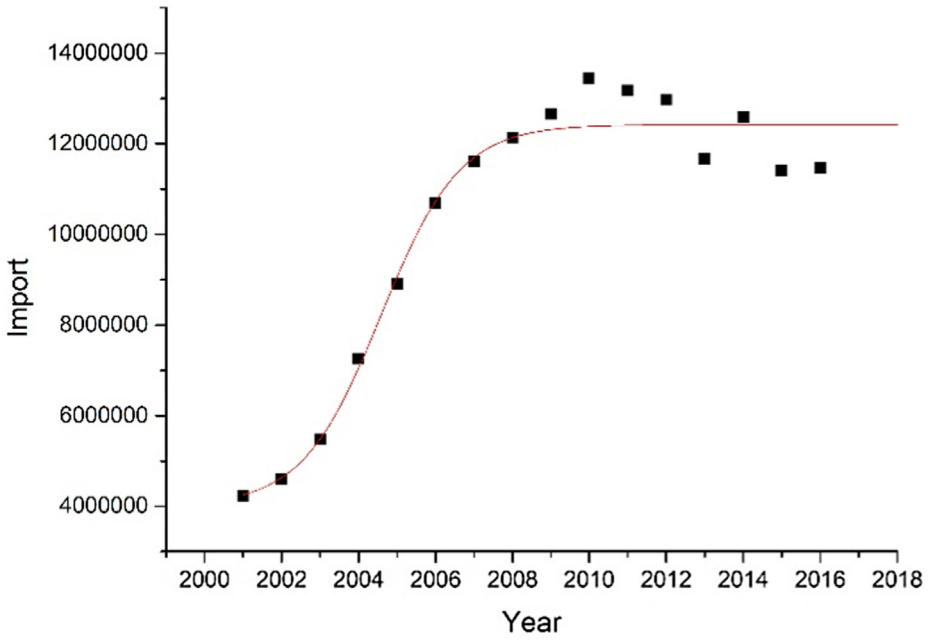


Fig. 2. Analysis and fitting of Asian plastic waste import trends, tons (R^2 = 0.95).

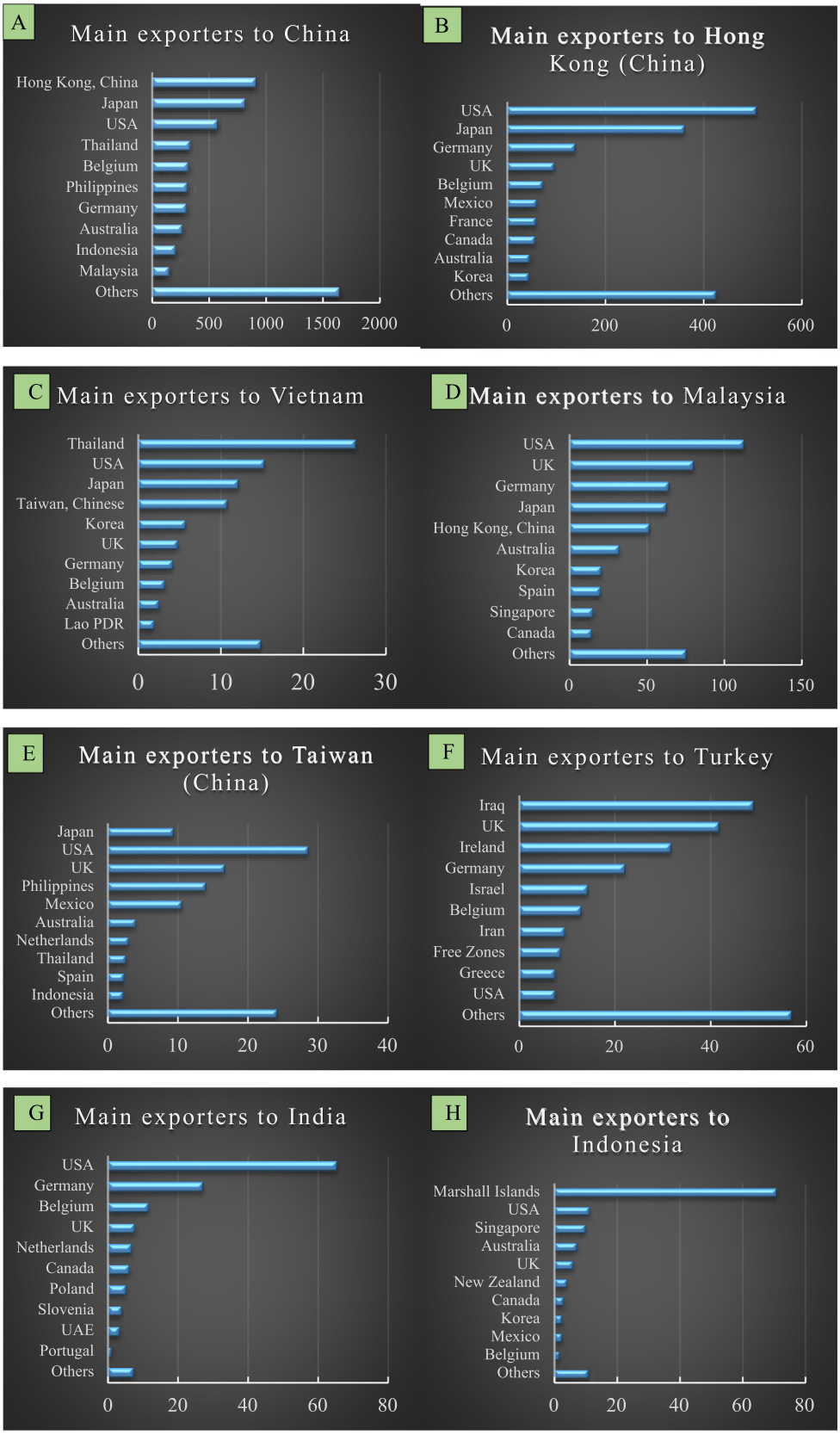


Fig. 3. Main plastic waste exporters to typical countries and regions in Asia (2017, kt). * "Plastic waste generation" is added here in order to balance input and output; it is not equal to the total waste generation.

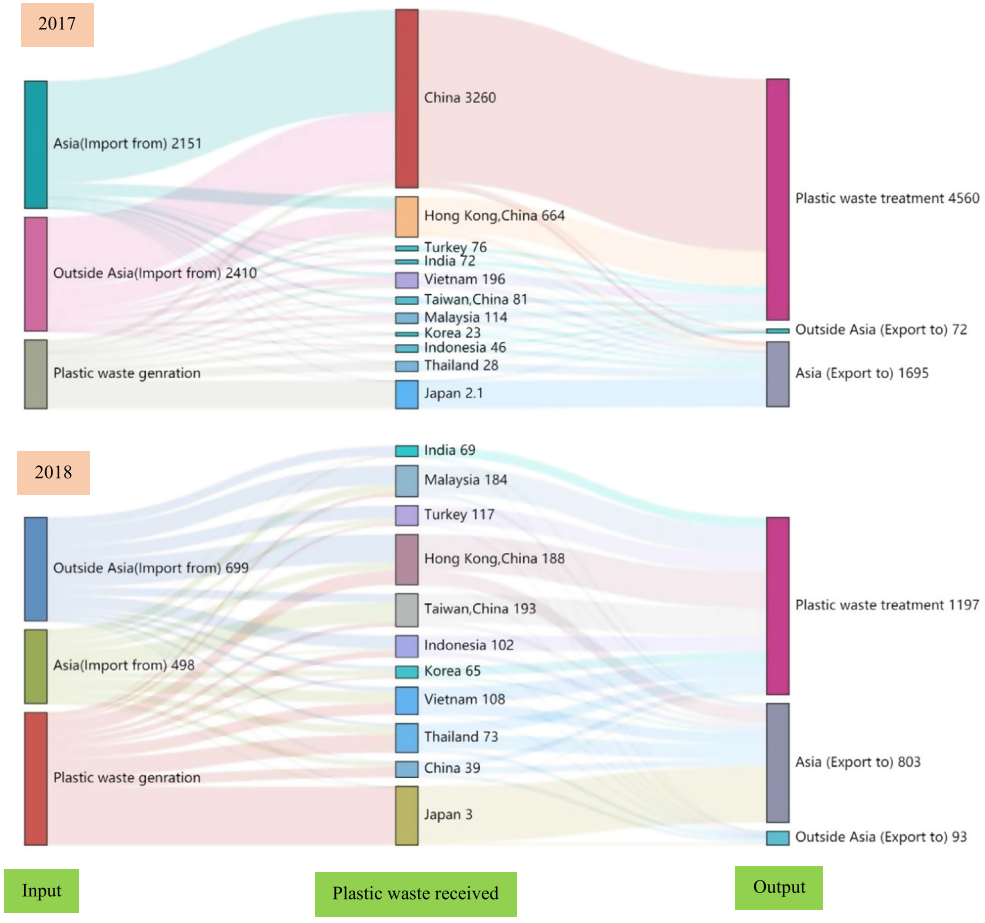
tities of 915 kt, 818 kt and 576 kt, respectively, made up about 40% of China's imports in 2017. In addition, the USA and Japan are also the main exporters to Hong Kong (China), Vietnam, Taiwan (China), India and Indonesia. More than 45% of the imports in Hong

Kong come from these two countries. Thailand is the top exporter to Vietnam, with 26 kt of plastic waste in 2017. Indonesia received more than 70 kt of plastic waste from the Marshall Islands. Based on data from the ITC, the Marshall Islands exported 30 kt, 71 kt and 93 kt of plastic waste to Indonesia in the years 2016–2018. However, it imported only 66 tons in 2017and generated 8.6 kt MSW in 2014. It may be importing hidden or illegal plastic waste. Other major countries exporting plastic waste to Asia include Germany, the UK, Ireland and Belgium. In total, Japan, the USA and Germany exported the most to countries and regions in Asia, with 1.37, 1.32 and 0.8 Mt total, respectively, in 2017.

Fig. 4 shows the plastic waste trade flow in typical Asian countries and regions in 2017 and 2018. It aims to analyze how much plastic waste is received from regions outside Asia, and the plastic waste Asia exported to other regions. The input portion includes imports from Asian countries or regions, imports from outside Asia, and some plastic waste generated within Asian countries themselves. The outflow is divided into exports to other regions in Asia, exports outside Asia, and plastic waste treatment within the countries or regions themselves. Countries with import values of less than 1% of the Asia are not counted here. In 2017, we can see that about half the plastic waste imported by Asian countries and regions came from other regions, most of the exports occurred within the Asia region, and equivalent to 98% of the plastic waste imported was left in Asia for disposal. China received most of the plastic waste; only a small part of it went to other Asian countries or regions. Hong Kong (China) has taken on the role of a plastic waste transfer station, and the main importer to Hong Kong was China (mainland), with a portion of about 96%. Compared to the plastic waste exported from outside Asia in 2017 and 2018, it can be observed that the plastic waste imported by Asia declined about 72% in monetary value. In 2018, the balance of plastic waste trade has shifted: Hong Kong (China) and Taiwan (China) have now become the largest importers of plastic waste. Moreover, 58% of plastic waste comes from outside Asia, and on the export side, only US's $93 million of plastic waste is exported to outside Asia. There is still a large gap between the plastic waste imported to Asia and the plastic waste exported from Asia.

To understand the nature of the trade per country and region, the export coefficient R ($R = \frac{Q_e}{W}$) and D ($D = \frac{Q_e}{Q_i}$) were calculated for the countries and regions in Asia (Fig. 5). Countries and regions whose R values were higher than the average R (in Fig. 5, countries or regions where the bar is higher than the dashed line) will be discussed further. Such R valule implies that country (j) exports more plastic waste than the average, whether generated internally or imported from other regions.

Based on the assumptions of the study method, in 2016, the main *Exporters* include Japan, Thailand, Korea, the Philippines and Singapore, with coefficient D's of 632, 4, 4, 29 and 26, respectively, indicating that those countries exported plastic waste



* "Plastic waste generation" is added here in order to balance input and output; it is not equal to the total waste generation.

Fig. 4. Plastic waste trade flow in typical Asian countries and regions (in millions of dollars), in 2017 and 2018.

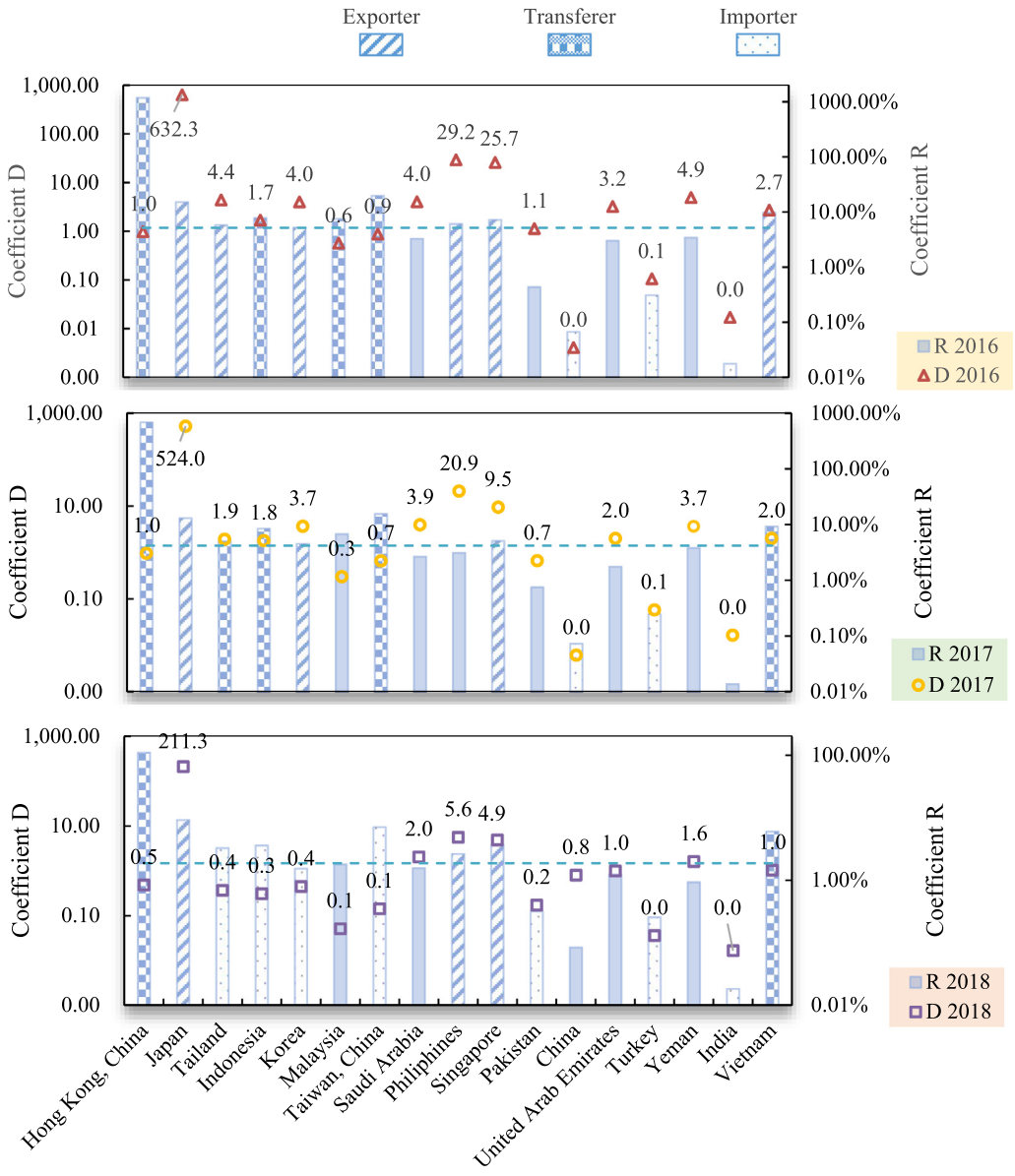


Fig. 5. The trade coefficient in Asia (The dashed lines represent average values of R in different years, $R_{average} = \frac{\sum Q_{ij}}{\sum W_j}$).

amounts far exceeding their imports. Hong Kong (China), Indonesia, Malaysia, and Taiwan (China) belong to the category *Transferers*, with data indicating that equivalent to 1, 1.7, 0.6 and 0.9 of the import quantities, respectively, were transferred to other countries. According to Edwin (2018) in the Asian Network Workshop, Hong Kong (China) imported about 29 Mt plastic waste, exported 1.4 Mt of domestic generation and re-export 28 Mt of its imports, in 2016. China, Turkey and India are recognized as *Importers*; their exports accounted for only 0.004 ,0.1 and 0.02 of the imports, respectively.

A country's role in the plastic waste trade can change, however, with policy trends. In 2017, Thailand became a *Transferer*, and Malaysia acted as an *Importer*. In 2018, Thailand, Indonesia, Korea, Taiwan (China) and Pakistan became main importers, while the transfer quantity of Hong Kong (China), with a D value of 5, declined noticeably.

Since 2017, Asian countries have begun to strictly limit plastic waste from western countries. Countries such as Vietnam, Thailand, Malaysia, the Philippines, and India have gradually tightened their import policies for plastic waste, including use measures to reduce permits, close illegal recycling facilities and ban the import of waste plastics. Combine with the analysis of trade roles countries played in those years, those measures are necessary.

4. Conclusion

Asia is the leading global manufacturer and trader of plastic waste, it manufactured about 131 Mt of plastic resins in 2015. The estimated amount of plastic waste generated by Asian countries in 2016 is about 121 Mt in total. Among the plastic waste trade, Asia imported 74% of the plastic waste globally, and China (mainland) imported the most plastic waste until 2017, with a quantity of over 5.8 Mt/year. In 2017, about half the plastic waste imported by Asia came from other regions, and most of the exports occurred within the Asia region. In terms of quantity, about 98% of the plastic waste was left in Asia for disposal. Based on the coeffi-

cients R and D, various countries' or regions' roles in the plastic waste trade were analyzed. It can be found that Hong Kong (China), Indonesia, Malaysia and Taiwan (China) acted as *Transferers* in 2016, and that the main *Exporters* included Japan, Thailand, Korea, the Philippines, and Singapore. The roles of many regions changed with policy trends. In 2017, Thailand became a *Transferer*, and Malaysia acted as an *Importes*. In 2018, Thailand, Indonesia, Korea, Taiwan (China) and Pakistan became main importers. These categorizations are based on import, export and waste generation data, although they are to some degree oversimplifications. Further tracking of the imported plastic waste flow can be studied in future research.

With the huge generation of plastic waste inside Asia and continually import of waste from outside, the formal management and recycling of plastic waste is less than satisfactory. From an extensive survey, the collection rates in most Asian countries are lower than 50%, and in some countries, there is a lack of technology and ability for plastic waste treatment even for the internally produced waste. Facing this situation, China began to restrict the import categories in 2017, and from 2018 on, China has comprehensively banned the entry of 24 categories of solid waste, including plastic waste. The effects of China's import restrictions on global trade and on domestic markets are already emerging. Affected by the ban on plastic waste in China, import quantities declined from over 7 Mt to 52 kt in 2018. The exports from Hong Kong (China) as well as the USA, Japan, and Germany have also been affected by import decrees. Other Asian countries also began to strictly limit plastic waste from western countries. Vietnam, Thailand, Indonesia and other countries have strengthened the management of plastic waste imports; some types of plastic waste that can create serious environmental pollution and cannot be handled domestically will be banned from entering. Regarding the current plastic waste situation, emphasis needs to be put on efforts both to the better recycle internally generated plastic waste and to manage the imported waste. The development of a circular economy and incentives for social participation in plastic waste collection and recycling are among the numerous pathways towards effective plastic waste management.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wasman.2020.09.049.

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