Plastic marine debris study based on Indonesian plastic national balance (IPNB) and seashore approach

A Z Abidin1 and S Steven1*

1 Department of Chemical Engineering, Institut Teknologi Bandung, Jl. Ganesha 10, Bandung 40132, Indonesia

* Email: soen_steven@students.itb.ac.id / soensteven@yahoo.com

Abstract. A clear and accurate plastic marine debris amount to clarify Indonesian marine debris issues still does not exist. Only Jambeck’s study estimated that millions of tonnes of plastic enter the Indonesian ocean every year, but the result is often disputed. This study, hence, was conducted to calculate the Indonesian plastic marine debris amount using Indonesian plastic national balance (IPNB) and seashore approach. The study was based on Indonesia’s 2019 data of plastic production, plastic raw material and finished-product balance, plastic recycling industry, plastic consumption, and plastic distribution. Indonesian plastic industries have a total capacity of 2.66 MT/y, production of 2.31 MT/y, import of 1.67 MT/y, and recycle of 1.655 MT/y. The results from Indonesian plastic national balance (IPNB) imply that after-used plastic of 5.755 MT/y is categorized into material still-consumed, material recycled, and plastic waste. About 90% of the plastic waste is managed which further recycled (0.654 MT/y) and ended up in the landfill (0.868 MT/y), while the rest (about 10%) is mismanaged and become marine debris (0.17 MT/y). For the results from the seashore approach, after-used plastic is burned and buried (3.228 MT/y), recycled (1.655 MT/y), ended up in the landfill (0.868 MT/y), flowed to the river (0.009 MT/y), picked up in the river (0.005 MT/y), and the rest become marine debris (0.004 MT/y). Both results differ from Jambeck’s calculation (0.48-1.29 MT/y) and therefore, clarify that Indonesia is not the second-largest contributor country for plastic marine debris.

1. Introduction

Plastic marine debris is a global environmental problem and challenging to Indonesia as a maritime country [1–5]. Due to rapid population growth in Indonesia, waste management infrastructure becomes unbalanced and poor [1,2,4,6–8]. Plastic is used in many aspects of daily life resulting in the accumulation of mismanaged plastic waste [9–13]. In many places, plastic waste is commonly seen along a beach and floating in the ocean. This condition makes plastic waste become a visible part of the marine debris problem [3,4,14]. In the ocean, plastic will continue to degrade into small pieces that difficult to be seen anymore, usually called micro-plastic if less than 5 mm long. Due to the low temperature of the ocean, the degradation process occurs slower than on the land [14–17]. It makes plastic marine debris truly threaten underwater living beings, such as fish, microorganisms, and can damage the marine ecosystem [3,4,18,5–8,11,14,16,17].

An accurate Indonesian plastic marine debris amount, however, still does not exist. Only Jambeck et al. (2015) estimated that millions of tonnes of plastic enter the Indonesian ocean every year. Nevertheless, the result from Jambeck’s study is still unclear and often disputed if compared to the ministry and recycling association data. Thus, it is necessary to clarify Indonesian marine debris issues with a more accurate approach. This study was conducted to calculate the plastic marine debris using...
There were three calculations in this study. Jambeck’s calculation as a baseline or control, then IPNB and seashore calculations for verifying Jambeck’s calculation. These calculations had several different parameters such as coastal population definition and determination, waste generation rate, percentage of plastic waste, and percentage of mismanaged waste. Jambeck assumed that Indonesian coastal population lived within 50 km from the ocean and the plastic marine debris calculation according to Jambeck’s calculation follows equation 1 [3].

\[
\text{Indonesian Plastic Marine Debris} = F \times CP \times PWG \times MPW = F \times CP \times WGR \times PPW \times MPW
\] (1)

where \(F\) is marine debris factor (15-40%), \(CP\) is coastal population within 50 km from the ocean (person), \(PWG\) is plastic waste generation rate (T/person/y), \(WGR\) is waste generation rate (T/person/y), \(PPW\) is percentage of plastic waste (11% for Jambeck’s calculation), and \(MPW\) is percentage of mismanaged plastic waste (%).

For IPNB calculation, the flow diagram should be generated in advance using the data adapted from the ministry of industry, Indonesian trade map, and INAPLAS. From this flow diagram, the after-used plastic will be recycled, still-consumed, and ended up as plastic waste. The plastic waste is then categorized as managed and mismanaged with the percentage referring to the IPNB flow diagram. According to this approach, the value of mismanaged plastic waste was equal to the Indonesian plastic marine debris. Subsequently, the determination of plastic waste generation rate (\(PWG\)) could be seen in equation 2.

\[
PWG = \frac{\text{Plastic Waste Amount}}{\text{Indonesian Population}} \rightarrow \text{Indonesian 2019 pop.} = 268 \text{ Millions}
\] (2)

For seashore approach, the Indonesian coastal population should be first determined by the data from Indonesian statistics 2019. Actually, the coastal population from Jambeck’s assumption is too far and absurd so this approach justified that coastal population lived in more than 10 km distance from the ocean. The seashore approach utilized coastal sub-district population which was calculated from the coastal district population in Java Island (\(JCDP\)), which follows the justification that Indonesian population is concentrated in Java Island [9]. The Indonesian coastal sub-district population calculation procedure was served in equation 3. The plastic waste generation rate calculation from seashore approach was identical to IPNB. Moreover, plastic flow diagram was also generated and the after-used plastic will be recycled, burned, buried, ended up in the landfill, thrown into the river, and picked up in the river [19]. Plastic waste entering ocean as plastic marine debris was calculated from the difference between the plastic waste entering river and the picked-up plastic waste.

\[
ICsDP = \frac{JCDP \times \%sD}{J}
\] (3)

where \(ICsDP\) is Indonesian coastal sub-district population, \(\%sD\) is percentage of sub-district population in Java, and \(J\) is Java population proportion.

3. Results and discussion
3.1. Indonesian plastic marine debris amount using IPNB
The Indonesian plastic capacity is 2.66 MT/y, the country production is 2.31 MT/y, imports 1.67 MT/y of plastic, and recycles 1.655 MT/y of plastic. The annual plastic production as well as import and recycle will then be consumed. Average plastic consumption is 21.47 kg/person/y which is much lower than neighboring countries Singapore, Malaysia, and Thailand which consume more than 60 kg/person/y [1,2]. The consumed plastic products are then distributed into seven categories: household, packaging, building, shopping bag, Styrofoam, others, and finished goods plastic import [1,2,9,10]. After-used plastic is generated after plastic consumption and becomes material still-consumed (53.2%), material recycled (17.4%), and plastic waste (29.4%). The plastic waste generation is 1.692 MT/y or equal to 0.017 kg/person/day. Afterward, about 90% of plastic waste is managed which is then thrown into the landfill and recycled again, while about 10% of plastic waste, 0.17 MT/y, is categorized as mismanaged plastic waste and entered the ocean. From the exposition above, a detailed plastic flow diagram based on IPNB is depicted in Figure 1.

Figure 1. Indonesian plastic balance based on IPNB, adapted from: [1,2,19].

3.2. Indonesian plastic marine debris amount using seashore approach
The seashore approach presumes that plastic marine debris comes from the river stream and due to the fishermen who throw the waste in the ocean. Plastic waste generated in the river initiates from the riverbank population which is concentrated in the sub-district area. The population is first determined from the coastal district population in Java Island (JCDP) which can be seen in Figure 2. The average % sub-district population in Java (%sD) is also calculated at 34.7% (Table 1) and approximately 56.3% (J) of the Indonesian population is concentrated in Java, as described in Figure 3. Therefore, the Indonesian coastal sub-district population occupies about 44.75 million people, as shown in Table 2.
Figure 2. Coastal district population in Java 2019 [9,20].

Table 1. Percentage of coastal sub-district population in Java [9,20].

| Sub-district | Sukra | Pandeglang | Surabaya |
|--------------|-------|------------|----------|
|               | 43884 | 33139      | Benowo   |
| Kandanghaur  | 86603 | 56455      | Asemrowo |
| Losarang      | 54033 | 35113      | Krembangan |
| Cantigi       | 31879 | 34657      | Pabeancantikan |
| Sindang      | 50563 | 51142      | Semampir |
| Indramayu    | 111009 | 35182    | Kenjeran |
| Balongan     | 38675 | 38409      | Bulak    |
| Juntinyuat   | 78644 | 23876      | Mulayorejo |
| Karangampel  | 63134 | 22190      | Sukolilo |
| Krangkeng    | 63944 | 52866      | Rungkut  |
| Sub-district | 622368 | 383029     | 527360 |
| Total pop. | 1718495 | 1194911    | 1473640 |
| % sub-district | 36.22 | 32.06 | 35.79 |
| Average % sub-district | 34.70% |
Figure 3. Indonesian province population in 2019 [9,20].

Table 2. Indonesian coastal sub-district population.

| Parameters                                      | Amount             |
|------------------------------------------------|--------------------|
| Coastal district population in Java             | 72,634,285         |
| Coastal sub-district population in Java         | 25,193,714         |
| Indonesian coastal sub-district population      | 44,749,048         |

Slightly differ to IPNB, the after-used plastic from seashore approach tends to be burned, except for shopping bag which is mostly recycled [9,10,12,13,19]. The rest will then be recycled, buried, ended up in the landfill, and thrown into the river with the percentage given in Table 3. The percentage of after-used plastic which is burned and recycled is quite similar for building sector whereas the percentage of after-used plastic which is buried and recycled is quite similar for automotive and electronics sectors. From Table 3, about 71.08% of the after-used plastic will be thrown in the landfill (0.868 MT/y) as well as burned and buried (3.223 MT/y), nearly 28.76% is recycled (1.655 MT/y), and the rest (0.16% or 0.009 MT/y) is thrown into the river. The river plastic waste of 0.005 MT/y is picked up and 0.004 MT/y enters the ocean. The detailed plastic flow diagram based on seashore approach is served in Figure 4.

Table 3. Percentage of after-used plastic calculation [9,10,12,13].

| Plastic Distribution Sector | Proportion (%) | Burned (%) | Recycled (%) | Buried (%) | To River (%) | Total Burned (%) | Total Recycled (%) | Total Buried (%) | Total to River (%) |
|-----------------------------|---------------|------------|--------------|------------|--------------|------------------|-------------------|------------------|-------------------|
| Household (Aneka)           | 31%           | 61.74      | 27.20        | 10.90      | 0.16         | 19.14            | 8.43              | 3.38             | 0.05              |
| Packaging                   | 33%           | 62.35      | 27.20        | 10.30      | 0.15         | 20.58            | 8.98              | 3.40             | 0.05              |
| Building                    | 6%            | 39.74      | 38.20        | 21.90      | 0.16         | 2.38             | 2.29              | 1.31             | 0.01              |
| Shopping bag                | 4%            | 19.35      | 69.20        | 11.30      | 0.15         | 0.77             | 0.97              | 0.45             | 0.01              |
| Automotive                  | 22%           | 49.74      | 24.20        | 25.90      | 0.16         | 10.94            | 5.32              | 5.70             | 0.04              |
| Electronics                 | 4%            | 49.74      | 24.20        | 25.90      | 0.16         | 1.99             | 0.97              | 1.04             | 0.01              |
| **Percentage of after-used plastic** | **55.80**     | **28.76**  | **15.28**    | **15.28**  | **0.16**     | **55.80**        |                   | **15.28**        | **0.16**          |
3.3. Comparison of Jambeck, IPNB, and seashore results

The results discrepancies between these three calculations lie in the different justifications for coastal population, the amount of waste generation, the percentage of plastic waste, and the percentage of mismanaged waste. Jambeck identifies that Indonesian coastal population is 187.2 million due to the population within 50 km from the ocean [3]. Also, the assumption for 11% of total waste is categorized as plastic waste and about 83% of total plastic waste is mismanaged [3,21]. Jambeck’s calculation on waste generation rate is 0.52 kg/person/day and the amount of Indonesian plastic marine debris is calculated 0.48-1.29 MT/y [3].

Contrary to Jambeck’s, IPNB and seashore presumed 44.75 million of coastal population. That is the population who lived within 10 km from the ocean with the justification that people are very rare coming to the ocean within 50 km of distance. According to Indonesian plastic product distribution data, plastic waste generation rate is only 0.017 kg/person/day [9,10,12,13]. Moreover, the percentage of plastic waste is only 9% [12,13]. The waste generation rate is then equal to 0.19 kg/person/day which is lower than Jambeck’s. IPNB calculation has a result of 0.17 MT/y of mismanaged plastic waste becomes plastic marine debris [1,2,9,10,12,13].

Also, seashore approach strengthens and complements IPNB results. The after-used plastic is thrown into the landfill, burned and buried, recycled, thrown into the river, and picked up. About 0.004 MT/y of plastic waste flow to the ocean as plastic marine debris. Both calculations prove and clarify that only a small part of mismanaged plastic waste contributes to plastic marine debris. The results comparison is outlined in Table 4.

4. Conclusions and future outlook
The plastic marine debris calculation using IPNB and seashore approach clarifies Jambeck’s calculation and claim. Based on this study, there is only a partial amount of mismanaged plastic waste entered the ocean. Both calculations give a lower amount of plastic marine debris than Jambeck’s. Jambeck’s calculation on Indonesian plastic marine debris is 0.48-1.29 MT/y, where the IPNB and seashore calculation resulting in 0.17 MT/y and 0.004 MT/y, respectively. Although Indonesia is not the second-largest contributor country for plastic marine debris, some activities either zero waste management education program; plastic recycling performance improvement; clean river, beach, and ocean maintenance, or trash trap installation on the river are also interesting to be offered in order to solve the plastic waste problem.
Table 4. Plastic marine debris calculation results comparison.

| Parameters                        | Units         | Jambeck | IPNB | Seashore |
|-----------------------------------|---------------|---------|------|----------|
| Indonesian coastal population     | million       | 187.2   | 44.75| 44.75    |
| Waste generation rate             | kg/person/day | 0.52    | 0.19 | 0.19     |
| Percentage of plastic waste       | %             | 11      | 9    | 9        |
| Plastic waste generation rate     | kg/person/day | 0.057   | 0.017| 0.017    |
| Plastic waste amount              | MT/y          | 3.89    | 1.69 | 1.69     |
| Mismanaged waste                  | %             | 83      | 10   | 10       |
| Mismanaged plastic waste          | MT/y          | 3.22    | 0.17 | 0.17     |
| Total plastic marine debris       | MT/y          | 0.48-1.29| 0.17 | 0.004    |

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