CHEMICAL ENGINEERING TRANSACTIONS
VOL. 103, 2023
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Petar S. Varbanov, Panos Seferlis, Yee Van Fan, Athanasios Papadopoulos

ISBN 979-12-81206-02-1; **ISSN** 2283-9216
DOI: 10.3303/CET23103049

Estimating E-commerce Plastic Waste of the Philippines through Fate Modelling

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The COVID-19 pandemic resulted in a sudden expansion of the e-commerce industry. This expansion incurred an increase in the use of packaging for e-commerce products, specifically plastic packaging. As the pandemic disrupted the global economy, global future sustainability needs to be reassessed. Assessing the sustainability of developing countries is imperative as developing countries influence global material flow. Notably, the Philippines is reported as a major contributor of plastic waste emitted to the ocean. Estimating the country’s plastic waste emission due to the e-commerce market growth is essential for foresight on the country’s sustainability. Therefore, this research aims to estimate and forecast the e-commerce plastic packaging waste in the Philippines. The research focuses on the fate of plastic packaging through the Plastic Leak Project (PLP) model. This study integrates literature data on e-commerce market size and trend, plastic packaging weight, and leakage ratios to the PLP model. The integrated model provided estimates of the plastic waste incurred by the e-commerce industry. Results showed that the Philippines emitted 11.79 kt of e-commerce plastic packaging. Compared with existing literature, the emission comprises 2.66 % of all plastic waste emitted. The results also showed that 0.42 kt of e-commerce plastic packaging was emitted to the ocean, comprising 0.12 % of the country’s total plastic emitted to the ocean. The percent contribution indicates that e-commerce plastic waste is unnoticeable. However, sustainability action plans are still needed in managing the growing e-commerce plastic packaging waste emission. Future research works may utilize the model as a sub-model of crave-to-grave life cycle models. The developed model may also be utilized in estimating and forecasting e-commerce plastic packaging waste in other countries.

1. Introduction

Global dependency on plastics entails a future with notable environmental impacts. Manufacturing, consumption, and disposal of plastics will result in environmental damages, such as climate change and aquatic life loss. The energy requirement for plastic production emits 1.7 Gt of carbon emissions in 2015. The plastic material, itself, has an inherent carbon stored with potential to emit an additional 890 Mt (Cabernard et al., 2022). Improper disposal results in aquatic life loss. Plastics emitted into the marine environment endanger marine life due to entanglement, ingestion, and interaction (Law, 2017). Ritchie and Roser (2018) estimated 381 Mt of plastics are disposed annually, detrimentally affecting marine ecosystems when not managed properly. Beaumont et al. (2019) determined that plastic emitted to the marine environment incur negative impact on the environmental, economical, and social aspects. They estimate that the impact incurs an annual economic cost of 3,300 to 33,000 USD per t. The COVID-19 pandemic aggravated plastic waste generation as e-commerce became a prominent product channel. Imposed lockdowns and fear pressured consumers to shift towards e-commerce services, such as food delivery, online delivery, and parcel delivery services. E-commerce services required the use of packaging materials with plastics as among the dominant one. Plastic packaging, however, is an environmental issue that remains to be resolved (Hao, 2021).
Interventions for plastic waste minimization is essential for sustainability. A necessary step before implementing interventions is the assessment of current plastic packaging issues. Studying the fate of plastic waste is a key research area in the assessment. Works, such as by Bungay (2017), analysed the kinetic properties of plastic waste thermal degradation. Another work is by Plohl et al. (2022) where they investigated plastic fragmentation

Paper Received: 03 April 2023; Revised: 05 July 2023; Accepted: 06 August 2023
Please cite this article as: Huan K.C., Martin C., Ocampo D., Gue I.H.V., 2023, Estimating E-commerce Plastic Waste of the Philippines through Fate Modelling, Chemical Engineering Transactions, 103, 289-294 DOI:10.3303/CET23103049

in an aquatic environment. Fate modelling is a key research area in the assessment of plastic packaging issues. Fate modelling quantifies the environmental implications and can act as a sub-model for Life Cycle Assessments (LCAs).

Fate of plastics is a concern for low-to-middle income countries as these countries constitute a majority in plastic wastes emitted to the ocean (Ritchie and Roser, 2018). The Philippines, for instance, contributes to one-third of the plastic waste emission, emitting 356.37 kt of plastic debris to the ocean (Meijer et al., 2021). In addition, the country consumes notable amounts of plastic packaging. GAIA (2019) estimates that the country consumes 17.5 billion plastic shopping bags per y, entailing 3.3 kg of plastic consumption per capita. Plastic wastes of the country rapidly increased amidst the pandemic as pharmaceuticals, e-commerce, and food industries responded to the disruption. The country's e-commerce industry is expected to grow as the Department of Trade and Industry (DTI) noted that the industry has a GDP share of 5.5 % in 2022 from 3.4 % in 2019 (Mordor Intelligence, 2022).

The e-commerce industry's growth will result to an increase in plastic packaging waste emitted to the ocean. Modelling the fate of plastic packaging is a requisite in the development of an action plan for plastic management. There is yet a study that determined the fate of e-commerce plastic packaging waste of the Philippines. Therefore, this study aims to estimate the plastic packaging waste emitted through fate modelling. This study estimates the fate through the Plastic Leak Project (PLP) model by Quantis (2023). PLP model is an emission-based mass balance model, reflecting the fate of plastics through compartments across different stages. PLP model is recognized among previous research works. Loubet et al. (2021) used the model to determine the fate of seafood products. Correla-Puertas et al. (2022) applied the PLP model for the fate of expanded polystyrene and tire wear microplastics. The PLP model's ability to track fate across the stages allows ease of integration to the LCA framework, enabling cradle-to-grave analysis. The model also provides macro-level insights that can complement national action plan development. This study also introduces a methodological framework that integrates e-commerce market characteristics, providing estimation specific to the e-commerce industry. The framework may be applied in the estimation of other countries' waste emission.

2. Plastic Leak Project Model

The Plastic Leak Project (PLP) model characterizes the fate of plastic waste through channels and compartments across five stages, as depicted in Figure 1. The PLP model can consider the fate of both microplastics and macroplastics. Microplastics are plastic sizes with less than 0.5 cm while macroplastics are those with greater than 0.5 cm (e.g., food containers, plastic bags). For this study, e-commerce packaging is considered as macroplastics. The model's five stages include 'loss', 'transfer', 'initial release', 'redistribution', and 'final release'. Flows of plastic waste are estimated using leakage ratio between the prior stages and the latter stages.

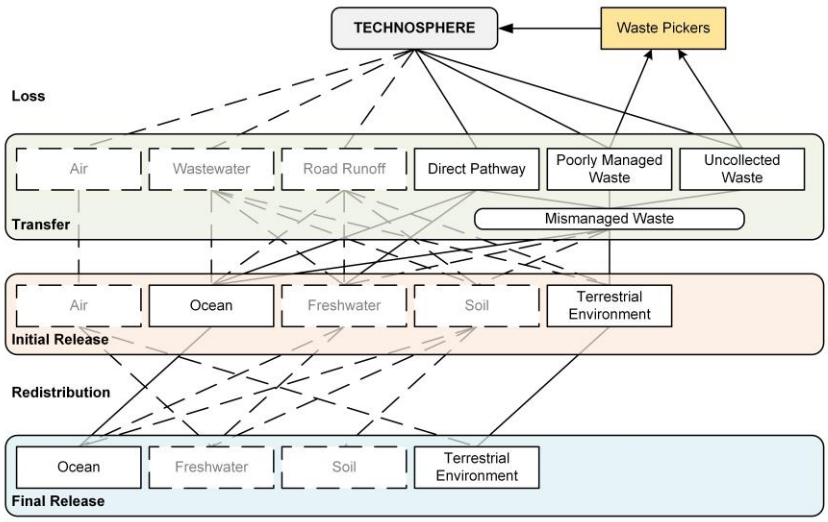

Figure 1: Conceptual framework of the PLP model (dotted lines indicate pathways not included in this study)

Plastic waste is, first, quantified from the technosphere. The technosphere encompasses the system where plastic materials are consumed. The plastic materials then enter the 'loss' stage. The 'loss' stage depicts the amount of plastics leaving the technosphere. Plastic losses include material lost during manufacturing, during utilization, and during disposal. The 'loss' stage channels the plastic waste to the 'transfer' stage. This stage

categorizes plastic waste into six pathways which include ‘air’, ‘wastewater’, ‘road runoff’, ‘direct pathway’, ‘poorly managed waste’, and ‘uncollected waste’. ‘Air’, ‘wastewater’, and ‘road runoff’ are pathways for the fate of microplastics. Meanwhile, ‘direct pathway’, ‘poorly managed waste’, and ‘uncollected waste’ are considered for the fate of macroplastics. ‘Direct pathways’ depict wastes that are directly disposed to the environment, such as dumping. ‘Poorly managed pathways’ reflect plastic disposal from poor waste management, such as illegal dumping and non-sanitary landfills. ‘Uncollected pathways’ are plastic wastes that were not properly managed. The PLP model assumes reverse channels are present for the latter two pathways as waste pickers can retrieve high valued plastics. Their retrieval returns the plastic waste back to the technosphere.
Plastic wastes from the ‘transfer’ stage are then categorized to the ‘initial’ release stage. The ‘initial release stage’ depicts emissions emitted to the environment, categorizing them into five compartments, ‘air’, ‘ocean’, ‘fresh water’, ‘soil’, and ‘terrestrial environment’. The ‘air’ compartment is directly transmitted from the air pathway of the prior stage. The other compartments are transmitted by the different pathways. The plastic wastes are then redistributed in the ‘redistribution’ stage. This stage reflects transfer of compartments due to potential material movements, such as leaching, water channels (e.g., rivers to oceans), and wind blows. Plastics are redistributed to the ‘final release’ stage where it meets its final fate.

3. Conceptual framework

This study develops a model integrating e-commerce data in estimating the industry’s plastic waste emission. Figure 2 depicts the design of the conceptual framework. Losses from the technosphere are estimated from the e-commerce market size, the e-commerce projected market growth, the average order value (AOV), the plastic packaging weight, the plastic packaging per order, and the leakage ratios. The market size reflects the purchase volume of e-commerce, indicating the purchase potential of the industry. In 2022, the Philippines’ e-commerce Philippines is 1.1 trillion pesos according to Gomez (2022) and International Trade Administration (2022). The market size has the potential to expand, and the expansion is based on projected market growth from literature. Mordor Intelligence (2022) estimated that the industry will have an annual growth of 11.4 % for the next 5 y. The e-commerce market size and growth, however, does not reflect the number of orders. AOV is, therefore, integrated to estimate the number of orders. AOV is a metric reflecting the average purchase value per order made. The Philippines has an estimated AOV of 2,887 pesos (iPrice, 2023). Integrating the three datasets yields the number of orders per annum.

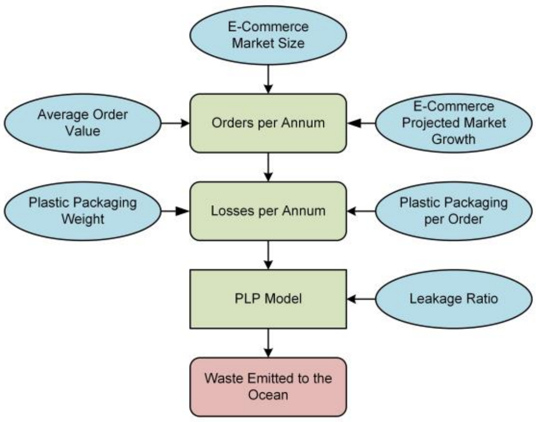

Figure 2: E-commerce plastic leakage model framework used in this study

The losses per annum are then estimated from the number of orders. Each order has an average number of plastic packaging used. This work assumes 2 plastic packaging per order. The plastic packaging per order is then multiplied with the packaging weight of 15.47 grams (Pilfold, 2013). Multiplying both data yields the losses from the technosphere. The losses are the input to the PLP model. PLP determines the fate of the losses according to leakage ratios. Table 1 outlines the leakage ratio applied in this study. Quantis (2023) has a country database of the leakage ratio from the loss stage to the transfer stage. Their data comprised of leakage ratios for mismanaged waste and unaccounted waste. Their data is based from the World Bank’s report on national government data (Kaza et al., 2018). This work assumes that the unaccounted wastes were returned back to the technosphere via the informal waste pickers. The leakage ratios for the transfer stage to the initial release stage were obtained from Biona et al. (2015) which are a conglomeration of government reports and literature data of Scheinberg (2011). The leakage ratios encompass both terrestrial and ocean compartments. Biona et al. (2015) also indicated 7 % of the mismanaged waste is burned. The burning pathway is not reflected in the

PLP model, resulting to its omission in the model. Redistribution rates reflect compartment transfers due to material movement in the environment. The rates were set to 100 % similar to the study of Quantis (2023), as no data was found reflecting redistribution rates.

Table 1: Assumed leakage ratios of the e-commerce plastic packaging

Channels	Leakage Ratio
Loss to Transfer	
Mismanaged Waste	72 %
Unaccounted Waste	28 %
Transfer to Initial Release	
Terrestrial	88 %
Ocean	5 %
Redistribution Rate	
Terrestrial to Terrestrial	100 %
Ocean to Ocean	100 %

4. Results and discussion

Figure 3 depicts the estimated fate of e-commerce plastic packaging waste. This study's model estimated that 11.79 kt of e-commerce plastic packaging are lost by the country from the technosphere in 2022. The World Bank (2021) estimated that the Philippines emits a total of 4,431 kt of LDPE and HDPE. Comparing this with the results, 2.66 % of the total plastic wastes are in the form of e-commerce plastic packaging. This study also estimated that 424 t of e-commerce plastic packaging are emitted to the ocean. Meijer et al. (2021) estimated that the country emits 356.37 kt of plastic to the ocean. Comparing this with the results, 0.12 % of plastics emitted to the ocean originate from the e-commerce industry.

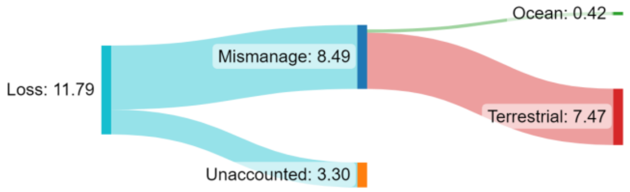

Figure 3: Estimated fate of e-commerce plastic waste in 2022 in kt

An uncertainty analysis was also carried out, varying from 1 to 3 packaging per order. Figure 4 reveals an estimated emission to the ocean from 212 t to 637 t in 2022. This would comprise 0.06 % to 0.18 % of the plastic emitted to the ocean. With market growth, the emission will be from 503 t to 1,510 t by 2030. Relative to the Meijer et al. (2021) data, this will comprise 0.10 % to 0.29 % of the current amount of plastics emitted to the ocean. These results indicate that there is low percent contribution of e-commerce plastic packaging waste to the total plastics emitted. Plastic management interventions may consider prioritizing other industries for significant reduction of total plastic lost from the technosphere.

The emission to the ocean constitutes 4 % of the total loss from the technosphere. From Figure 3, the relative low percent contribution is due to the low leakage ratio from the 'transfer' stage to the 'initial release' stage. The limitation of the model, however, is the assumption that no redistribution occurs. In the long-term, the emission to the terrestrial environment may end up in the ocean. Proper plastic waste management is still needed to minimize the lagging plastic emission as redistribution occur in the long-term.

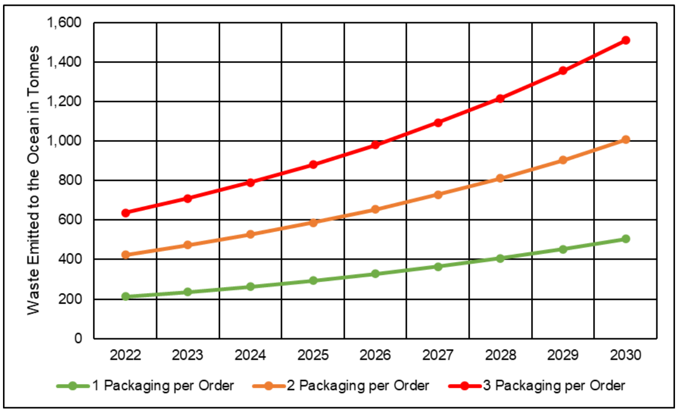

Figure 4: Uncertainty analysis on plastic packaging per order of the estimated e-commerce plastic waste

The model also assessed scenarios based on consumer behaviour and on waste management. Figure 5 presents the result of the scenario analysis. On consumer behaviour, purchases may be done more frequently as e-commerce becomes a dominant product channel. The model was subjected to a decreasing AOV from 2022 to 2030 at a rate of 8.3 %, resulting to consumers purchasing twice as frequent by 2030. The scenario analysis revealed that there will be an exponential increase in plastic waste emission, two-folds compared to the baseline trend. This will yield 2,013 t of e-commerce plastic waste emitted to the ocean by 2030, comprising 0.56 % relative to the current amount of plastic wastes emitted. Similar to the earlier results, the scenario analysis revealed low percent contribution of e-commerce plastic waste.
Another scenario is the improvement on waste management. The scenario assumes that the leakages ratio of 72 % mismanaged waste will reach 50 % by 2030, at a decreasing rate of 2.75 %. The scenario is based on the recommendation of World Bank (2021) which considers restricting the disposal of plastic. Results show a decreasing waste emission per annum with the potential to avert a cumulative of 1.01 kt of plastic wastes by 2030. Proper waste management, e.g., restricting disposal of plastic, can help minimize and manage e-commerce plastic waste.

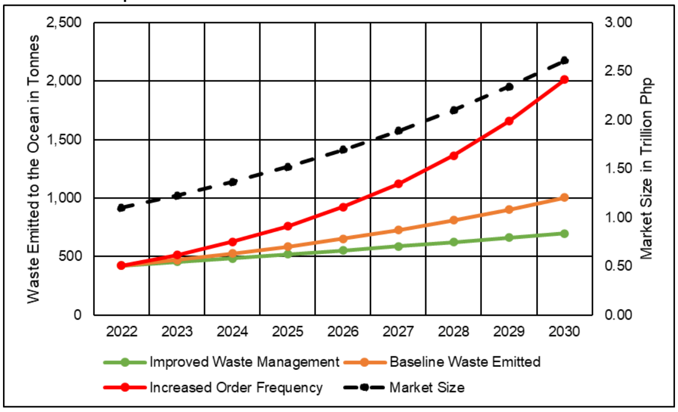

Figure 5: Scenario analysis of future e-commerce plastic waste

5. Conclusions

This work estimated the Philippines' e-commerce plastic packaging waste to the ocean from 2022 to 2030. The study designed a methodological framework integrating market characteristics, plastic packaging characteristics, and the Project Leak Project (PLP) framework. The study revealed that e-commerce has a minor contribution when compared to literature estimates. This finding indicates that other industries' plastic waste can be prioritized for significant reduction. This work also found low leakage ratio to the ocean. However, the long-term fate may redistribute terrestrial plastic wastes into the ocean. This work recommends proper waste management to avert long-term impact.
A limitation of this study is in the model's validation. The calculations are based from literature data, providing rough estimations of the material flow. Future studies can hold a workshop to validate the findings of this work. Additionally, the parameters for forecast are anchored on economic trends. Socioeconomic parameters are not

included in the forecast. Socioeconomic parameters can, however, disrupt market trends. Future studies may expand the model in integrating the additional dimensions. Lastly, the study assumed that no redistribution took place. The limitation may be resolved by future study through tracking of plastic waste after the 'initial release' stage.

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