Multivariate input-output analysis model to better estimate of future plastic waste generation: Case study of waste electrical and electronic equipment (WEEE)

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INTRODUCTION

Europe, as the third largest plastic producer after Asia and North America countries, produced 29 Mt of plastic waste in 2019, in which 33% is sent to recycling facilities and the rests are either landfilled or incinerated (SYSTEMIQ, 2022). However, several studies indicate that a significant amount of plastic waste (i.e., 7 – 15 Mt) are 'missing' and not accounted for in the statistical database (SYSTEMIQ, 2022; Agora Industry, 2022). These studies suggest that one of the reasons for the 'missing plastic' is underestimation of the product lifespans of plastic containing appliances (SYSTEMIQ, 2022; Agora Industry, 2022). Plastics have been widely used in electronic and electrical equipment (EEE) and from the total collected post-consumer plastic waste in 2018, 6% was found in waste electrical and electronic equipment (WEEE). To date, we still have limited knowledge to predict the evolution of material composition, stocks and flows of (W)EEE, which leads to an underestimation of WEEE generation (Lase et al., 2021). Specifically for plastic in WEEE (also known as WEEP), the quantities are underestimated because of the fact that WEEE are not disposed of immediately at the end-of-life. Small devices (e.g., electric shavers) can be hibernated in consumers' possession before being disposed of. Therefore, current approaches to quantify WEEP generation such as disposal rate analysis, projection models, and using fixed average lifespan estimation are perceived to be inadequate to estimate total WEEE generation (Lase et al., 2021). In the context to improve the estimation of plastic waste generation, the multivariate input-output analysis (MIOA) model is developed and applied. As system boundary, this research focuses on WEEP generation in Belgium and The Netherlands in 2030 and focuses on three selected small household appliances (SHA) being coffee machines, electric shavers, and vacuum cleaners.

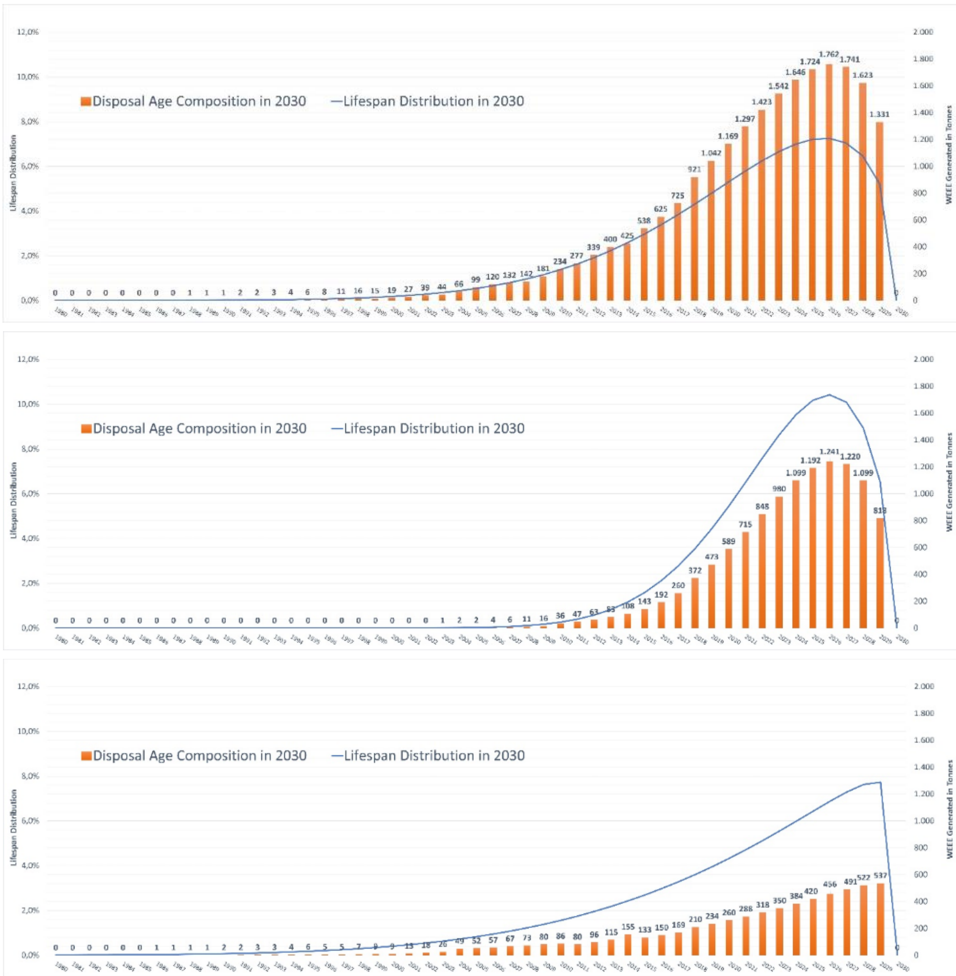
MATERIAL AND METHODS

The MIOA model considers the dynamic interconnection of product sales, stocks, and lifespan of EEE product obsolescence rather than the assumption of fixed or averaged product lifespan (Wang, 2014). With MIOA we would be able to predict the percentage and amount of EEEs that are accumulated in the market (as stocks) and flowing out as WEEE based on product lifespan (owing to the year of product sales) or time of disposal by consumers. The result is disposal age composition [*W (t,n)*], which describes and estimates the composition of WEEE generation at a given time (i.e., in 2030 for this study) based on their historical sales data [*POM (t)*] and EEE lifespan distribution profile [$L^{(p)}$ *(t,n)*]. The disposal age composition describes the amount of WEEE from the past (year *t*) being disposed of in the evaluation year *n*, which is in 2030 in this research. The historical sales data refers to the sales of vacuum cleaners, coffee machines, and electric shavers from 1980 to 2018 found in Eurostat database. The lifespan distribution profiles [$L^{(p)}$ *(t,n)*] are modelled using Weibull Distribution function chosen after Wang (2014) study. The lifespan distribution describes the probable obsolescence rate of EEEs in evaluation year *n* (i.e, 2030 for this study) of the batch of products sold in historical year *t* (1980 to 2018 from Eurostat data).

RESULTS AND DISCUSSION

The model results allow us to estimate the composition of the WEEE generated in 2030 (Figure 1) as well as the legacy chemicals there in, for example the brominated flame retardants (BFRs) content. In Figure 1, we can observe that a considerable amount of WEEE generated in 2030 might originate from the products purchased in 1990 – 2010. A considerable amount of WEEE purchased before 2010 can be explained by the fact that some of the electronic products have a slower disposal rate (blue curve in Figure 1) caused by for example hibernation in the consumers' possession or slow technological advancement in the market (Lase et al., 2021). The disposal composition can also be used to assess legacy chemicals for example the use of BFRs has been restricted in 2006 by the European Commission. However from Figure 1, we can fairly expect 1%–9% of the WEEE generated in 2030 might still contain

BFRs, which require a segregation of mixed WEEP containing BFRs at recycling facilities. In this context, BFR separation process, such as XRT, XRF or density separation will still remain relevant in 2030.



(A)
(B)
(C)

Figure 1. Disposal age composition and lifespan distribution profiles of (A) vacuum cleaners, (B) coffee machines, and (C) electric shavers waste in Belgium and The Netherlands in 2030

CONCLUSION

The multivariate input-output modeling approach to estimate WEEE and WEEP generation can be used to better predict the amount of waste generated in the future, minimizing the amount of 'missing plastic' and evaluating the potential legacy chemicals therein. As shown in this study, such modeling approach has been applied for small appliances and further research can be done for the other waste categories (e.g., large appliances) or other sectors too (e.g., automotive or building and construction).

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