Technical and Environmental Performance of Material Recovery Facility for Separately Collected Packaging Waste

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Material recovery facilities (MRFs) play an important role in municipal solid waste (MSW) systems as they provide a way to separate the different waste fractions according to their main physical properties (Tanguay-Rioux et al., 2021), therefore often determining the amount of collected recyclable material that can be recovered for recycling (Pressley et al., 2015). Mathematical models have been developed to assess the performance and design of these material separation systems, in which efficiencies can be captured through experimental methods or through physical modelling (Wolf, 2003). However, industry surveys and benchmarks for MRFs are scarce and the data on process efficiency are mostly unavailable (Mastellone et al., 2017). High quality data regarding aspects such as waste composition, impurities, sorting technology, purity targets, equipment performance, properties of final recovered material, residual contaminants, direct emissions, fuel and energy consumptions are required to ensure a reliable assessment of the technical and environmental performance of a MRF (Ardolino et al., 2017).

The present study aims to evaluate the overall environmental impacts related to the sorting of separately collected packaging in a MRF in the Lisbon region in Portugal, by Life Cycle Assessment (LCA), using operational and experimental data. This paper focuses on the development of a robust and specific MRF life cycle inventory (LCI), through the collection of operational data from a MRF and characterization data of all output waste streams obtained through a sampling campaign. The LCI and the experimental data was used to compare the environmental performance of two scenarios, with and without recirculation of residual waste in the MRF. This ultimately helps to address the question of how much we gain from recirculating and if these benefits offset the increased operational impacts. A MRF model was developed by resorting to the partition coefficients obtained from the sampling campaign in a MRF facility. This campaign, which was carried out in accordance with the standard ASTM E1107-15 (ASTM International, 2016), involved the characterization of the output streams, namely ferrous and non-ferrous metals, beverage cartons, plastic film, PET, HDPE and mixed plastics, which are sent for recycling. These streams were obtained after the facility was emptied and then operated for one hour with a regular quantity of input. Samples were then collected from each output stream and characterized by material type. This campaign allowed to obtain reliable data for the mass flows of the different materials throughout the stages of the sorting process and to obtain a set of partition coefficients for each of the outputs of a plant as a function of the input stream. Based on the model results, a LCA was carried out resorting to an attributional approach and by using the software package SimaPro®. The functional unit is the treatment of one metric ton of separately collected packaging waste processed in the MRF. The system boundaries include all the activities from the entry gate of the MRF until the management of all process products and residual waste. The foreground system includes only the MRF, whose related data is of high quality as it was derived from operational data. The background system includes the management processes of the products and residual waste, namely recycling, landfill and incineration, derived from the Ecoinvent 3.8. database. The substitution achieved through recycling and energy recovery is also considered in the LCA and modeled using the avoided burden approach. The recycling process LCIs collected and adjusted by (Haupt et al., 2018) were used as well as the processes for the substitution of recovered materials. The LCA study uses the ReCiPe midpoint method. Using the mass balance from the MRF model and the determined separation efficiencies, the recovery rates for all recycled materials were obtained and the environmental impacts results are shown in Table 1.

These results show that the increased output from recirculation more than compensates for the increased environmental impacts of the facility in one category (global warming), but in the remaining categories the results are either negative (i.e. recirculation does not bring benefits) or the net benefits are small (e.g., eutrophication). The main reason for this is that there is an increase of 17% of recovered materials, but the recirculation rate is 24%, i.e. the throughput increases by this value. In the case of global warming, the benefit from recirculation results from the substitution of virgin materials, but more significantly from the avoided emissions from burning the residual fraction of plastics. Also noteworthy is that the most valuable materials are already collected in the first round (e.g., PET, HDPE, ferrous metals), and, contrarily, there is a significant increase in the typically non-target materials, namely film, mixed plastics and beverage cartons. The results suggest that recirculation compensates for the material substitution alone, but its benefits are even more significant if it allows to divert plastic waste from waste-to-energy. These results might not hold to older or less efficient MRF, with higher energy footprints (more than 49 kWh/t) and higher electricity emission factors.

Table 1: LCA impacts for no recirculation and recirculation scenarios

		No Recirculation		Recirculation	
Impact Category	**Unit**	**Characterization**	**% vs. no recirculation**	**Characterization**	**% vs. no recirculation**
Global warming	kg CO2 eq	-565,77	100%	-1 454,44	207%
Stratospheric ozone depletion	kg CFC11 eq	-0,01	100%	-0,01	81%
Ionizing radiation	kBq Co-60 eq	-4,52	100%	-2,47	44%
Ozone formation, Human health	kg NOx eq	-7,46	100%	-7,05	76%
Fine particulate matter formation	kg PM2.5 eq	-3,72	100%	-3,78	82%
Ozone formation, Terrestrial ecosystems	kg NOx eq	-7,81	100%	-7,45	77%
Terrestrial acidification	kg SO2 eq	-8,76	100%	-8,48	78%
Freshwater eutrophication	kg P eq	-0,12	100%	-0,13	86%
Marine eutrophication	kg N eq	0,25	100%	0,17	55%
Terrestrial ecotoxicity	kg 1,4-DCB	-5 507,84	100%	-5 367,31	78%
Freshwater ecotoxicity	kg 1,4-DCB	3,50	100%	2,79	64%
Marine ecotoxicity	kg 1,4-DCB	1,03	100%	0,47	37%
Human carcinogenic toxicity	kg 1,4-DCB	192,66	100%	204,63	85%
Human non-carcinogenic toxicity	kg 1,4-DCB	-488,91	100%	-560,66	92%
Land use	m2a crop eq	-300,89	100%	-361,97	97%
Mineral resource scarcity	kg Cu eq	-33,52	100%	-36,19	87%
Fossil resource scarcity	kg oil eq	-1 536,38	100%	-1 515,05	79%
Water consumption	m3	-27 693,76	100%	-15 051,29	44%

It is important to note that the used coefficients are static and are restrained to a specific waste composition and operating conditions, but some deviations are expected with varying waste composition and flow rate. It was assumed that all the materials recovered in the MRF were effectively recycled, which in some specific cases, such as mixed plastics, can be an overestimation based in personal communications. Future work will focus on a similar question but at the collection stage, which will further help to understand the trade-off between higher recycling rates and the environmental impacts related to fuel consumption, vehicle use, among other (Pressley et al., 2015). Together, the results of the two studies will help to weigh the environment burden between the collection and the sorting stage. Additionally, a more detailed analysis of the disposal options for residual waste, and avoided emissions associated with the recovered materials is essential to ensure a deeper understanding of the role of MRFs in MSW management.

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