How to tackle plastic waste realistically? The case of packaging and service ware in the fast food industry in Semarang, Indonesia

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Abstract

Globally, Indonesia is the second largest generator of unmanaged plastic waste. The Indonesian government aims for a reduction of plastic waste of 70% by 2025. One of the main contributors to the problem is packaging waste of fast food restaurants. In this paper the packaging waste of twelve fast food chains in Semarang (Java) is analysed, and its environmental impact assessed by calculating plastic and carbon footprints in the period of 2019-2022. For each chain, between 30-100% of the restaurants in Semarang are included in the research, representing a sample of half the locations. Subsequently, five possible solutions, taken from the 10R circularity model, are discussed, showing that the options 'recycling' and 'waste-to-energy' are most feasible. Also, it is found that return rates are lagging behind, so the collection system should be improved to create economies of scale and to minimize volumes of unmanaged waste. Also, 'reduce' is a good scenario, volume wise it has less impact yet it has no disadvantages and may create awareness amongst consumers. 'Renew' may contribute to recycling by changing material composition of the packaging. 'Reuse' is not recommended as cleaning causes high carbon footprints. The other five Rs were not applicable in this case. Issues for further research include obtaining better data on packaging plastics volumes as sources are inconsistent, exploring options to improve collection and to avoid competition between recycling and waste to energy. It is finally concluded that reducing plastic waste from fast food chains can significantly contribute to reducing marine litter.

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Worldwide there is an enormous increase in packaging and service ware, leading to an ever increasing waste stream of plastics. Since the 1950s, total global production of plastics has grown to about 8.3 billion metric tons annually (Geyer et al., 2017). In the top ten of waste items most often found in coastal debris clean ups across the world are single-use plastic food ware items such as food wrappers, plastic beverage bottles, plastic bottle caps, as well as plastic cups and plates, and straws & stirrers (Ocean Conservancy, 2022). Many originate from fast food or take-away restaurants whose use further increased due to home delivery during the COVID-19 pandemic. Developing countries generate a relatively high amount of unmanaged waste (OECD, 2023). Due to lack of resources and poor infrastructure much of this waste is unmanaged, i.e. not treated properly or not collected (Breukelman et al., 2019). As a result of poor-solid waste management practices, plastics enter the ocean via rivers, wastewater outflows, and by currents, wind or tides. There are clear links between the increasing quantities of mismanaged managed plastic waste (MPW) and rising incidence of urban floods (MacAfee and Löhr, 2023). Both environmental problems share root causes linked to climate change and urbanization.

On land, plastic waste is also causing problems such as littering and soil pollution (Chae and An, 2018; Geyer et al., 2017). MPW may also lead to increased risk for urban landslides (MacAfee et al., 2024). Moreover, the water-, energy- and material use in the supply chain of plastics contributes to resource depletion and climate change (Shen et al., 2020). However, also developing and transition economies commit themselves to legally binding global instruments on environmental issues such as the resolution to end plastic pollution UNEP (2023). This means that all countries have to contribute to reducing marine litter and plastic pollution thereby saving natural resources and nature at large. Several initiatives exist with regard to cleaning oceans and river deltas, yet, it is better to tackle the problem upstream, at the source, hence on land.

Indonesia is the second largest generator of unmanaged plastic waste in the world, after China. Moreover, the Indonesian government aims to reduce marine plastic debris by 70% in 2025. In 2010, in Indonesia, unmanaged, i.e. non-collected and/or non-treated waste rates were 83% (Jambeck et al., 2015). The national target of solid waste management (Presidential Decree No 97/2017) is a 30% of solid waste reduction and 70% of plastic waste in the period of 2017-2025. However, one may expect that raising middle class incomes and status of eating out in fast food chains, result in further increasing volumes of packaging waste and service ware (plates and cutlery), which for the most part consist of plastics. Other issues are little resources and poor infrastructure for waste management, yet growing wealth for middle class hence tax raising potential and a growing awareness among citizens (Setya, 2020). Also, circularity can help to reduce both waste volumes (called plastic footprint in this research) and carbon emissions (Krikke, 2011).

Cramer (2017) describes 10 possible "R" options of MacArthur foundation. Packaging and service ware should also apply some of these options. The key question in this paper is which of these options are feasible for packaging waste in fast food in Semarang, Indonesia. Reduce, refuse and renew options promote more sustainable products and packaging early in the life cycle by looking at the design and material composition, for example biodegradable packaging or even elimination of packaging. The downstream "Rs" are reuse, repair, refurbish, remanufacture, recycle, repurpose and recover (waste-to-energy). Reuse, refurbish, and repair options are more feasible when the returned item is still in reasonable condition. Once obsolete or beyond repair, material recycling can be applied. As a final option, incineration combined with energy recovery is applicable. However, at the time of research (2019-2022), much waste is still not collected and/or treated at all.

This paper aims to develop a realistic approach to improve treatment of packaging waste and service ware from fast food chains. In order to cope with growing waste volumes of discarded fast food packaging and service ware we pose the following research question: *how can the city of Semarang improve its waste treatment towards circularity?* We conducted a case study in the city of Semarang as a representative example of urban waste management in developing economies. Typical of this case are growing volumes of unmanaged waste, partly from local and partly from global fast food chains, and the presence of a river delta connecting land and sea; ultimately creating marine litter. In line with government policies, the environmental impact should be reduced. To this end, we measure both the volumes of waste treated and processed by one of the Rs of the above framework called plastic footprint and as well as the carbon footprint. Furthermore, we look at other factors such as cost and infrastructure.

We consider five R options; applying (i) reuse, (ii) recycling or (iii) waste to energy to the collected waste. Next, we look at (iv) a reduction scenario (no straw) and (v) re-new possibilities. The choices of the R's used in this study are based on the important practices seen in the fast-food chains and we chose those that are most relevant in our case study. In these fast food chains the use of plastics can be very high. In the research focus was on specific action that could be taken in line with the guidelines stemming from the plastic stewardship model and related frameworks. This resulted in the focus on 1) reduction and minimization of their plastic usage footprint and 2) recycling and reusing plastic waste. Both steps would contribute significantly to a smaller and more closed-loop systems in line with the circular economy and new plastics economy frameworks. Refurbishing, remanufacturing, repair, repurpose and refuse are not considered relevant due to technical or functional limitations. Moreover, the local infrastructure can provide capacity to actually apply these five R options mentioned, even though energy recovery is relatively recent.

PACKAGING WASTE IN THE FAST FOOD INDUSTRY: THE CASE OF SEMARANG, INDONESIA

GENERAL BACKGROUND

Whether on land or in water, growing plastics volumes raise concerns about the risks and possible adverse effects to marine and aquatic organisms, ecosystems, and human health (GESAMP, 2016; Hantoro et al., 2019). Moreover, they negatively affect economic activities such as shipping, fishing, aquaculture, tourism, and recreation. UNEP (2014) estimated the economic impact on oceans of at least $8bn per year (UNEP, 2014). Litter is also a cause of floods in cities around the world due to the blockage of drains and sewerages (Hoornweg and Bhada-Tata, 2012; Kaza et al. 2018; Wilson et al., 2015).

Indonesia is the second largest generator of non-treated plastic waste in the world after China, mismanaging approximately 3.22 million ton, which is 10.1% of total non-treated plastic waste worldwide. This translates into 0.48 – 1.29 million ton of plastic marine debris per year (EcoBali, 2019; Ecobusiness, 2018; Jambeck et al., 2015) Although some studies come to lower estimates of annual inputs of plastic litter into the sea (Lebreton et al., 2017, Meijer et al., 2021, Veiga et al., 2023). Sampling waste from waterways around 15 coastal cities in Western and Central Indonesia (Bali, Lombok, Java, Kalimantan, Sulawesi and Sumatra) waste found in these waterways consisted for 31% of plastics (16% plastic bags, 1% plastic bottles, 5% plastic packaging, 9% other plastics), 21% of diapers, 4% of glass and metal, and 44% of other organic waste (EcoBali, 2019; WorldBank, 2018).

Although the government is taking important steps in improving Indonesia's waste management legislation, practice lags far behind. Plastic waste streams are usually not separated from other solid waste streams and municipal solid waste collection coverage (meaning the percentage of population having access to waste collection) only ranges between 45 and 50% in Indonesia (EcoBali, 2019; Sidik, 2010; Sudibyo et al., 2017). The most common practice of after-use collected solid waste management is disposal in landfills (66%). The remainder of the waste is recycled (4.6%), composted (7%), waste-to-energy (2.4%) and unmanaged waste (19.4%) (EcoBali, 2019). According to the Indonesian Ministry of Environment and Forestry (KLHK, 2019), of the total plastic waste generated in Indonesia, 10-15% is recycled, 60-70% is buried in landfills, and 15-30% is unmanaged, potentially leaking into the environment, especially into rivers, lakes and the sea (KLKH, 2019), Adding the non-collected waste to this number would totalize unmanaged to 70-80%.

Many plastic items found in Indonesian waste are used in the fast food industry. This industry is large in Indonesia - research shows that approximately 55 million Indonesians aged over 14 years (or 34.3% of the total population) eat in fast-food restaurants, buy take-away, use drive-thru, or order home delivery at least once every six months (Roy Morgan, 2018). However, a small group of Indonesians (approximately 9.5%) eat in fast food restaurants once per week or more. As Indonesians become more cash rich and time poor, they are consuming more fast food (Roy Morgan, 2018).

Semarang is a city on the north coast of the island of Java. Semarang is the capital of the province of Central Java and the fifth largest city in Indonesia (Rockefeller, 2016). It has a population of approximately 1.7 million people, occupying a total area of about 373 square kilometres, strategically located at a coastal delta (EcoBali, 2019; Rockefeller, 2016). Semarang is facing an economic transition from an industry-based economy to services and trade. Approximately 14% of GDP comes from trade, hotels and restaurants, and this is expected to increase (Rockefeller, 2016).

In 2016 ranked Semarang as one of the five cities with the largest leakage of plastic waste to the sea in Indonesia (Worldbank, 2016). Semarang's water supplies are directly threatened by this plastic leakage, and other domestic and non-domestic wastes, as 70% of the drinking water is supplied by surface water (Rockefeller, 2016). With a population of 1.7 million and a waste per capita of 0.73 kg/day, Semarang generates approximately 1,226 ton per day (EcoBali, 2019; KLKH, 2018). Waste management is poor, with the municipal government's waste collection service only managing to pick up 34% of the total waste in 2013, which is lower than the Indonesian average (Rockefeller, 2016). Most of the waste ends up at the Jatibarang Landfill which has been in operation since 1992. The typical composition of waste generated in Semarang is 61.2% organic waste, 16.3% plastic, 11.0% paper, 7.1% fabric, 1.3% metal, 1.8% glass, and 1.3% Others. Waste sample in the river delta in Semarang consisted for 35.3% of plastic waste (0.6% plastic bottles, 1.3% plastic cups, 14% plastic bags, 17.1% plastic packaging, 2.4% other plastics) (WorldBank, 2018). Recently, collection rates have improved but it is estimated that still the total volume of marine litter generation in Semarang may reach 47.6 tons/day or equivalent to 17,374 tons annually (Bintari, 2019). In the appendix we list the abbreviations used for plastics relevant in footprint calculations.

Mapping packaging chains of fast food restaurants in Semarang (base case)

In Semarang 12 fast food chains were studied using a quantitative methodology consisting of the observation, analysis and calculation of a yearly footprint of packaging and service ware provided to fast food customers. From each chain, between 30-100% of the restaurant locations in Semarang were included in the research (average of 51%). Each chain was categorized based on origin (international Chains 1-5 or local chains 6-10) and type of food. Note that for confidentiality we use abbreviations CH for chain followed by the number and a brief description of the main dish. CH1: Burgers, CH2 Chicken, CH3 Burgers CH4 Pizza, and CH5 Coffee & snacks; CH 6 Asian, CH 7 Asian, CH8 Coffee & snacks, CH 9 Asian, and CH 10Asian) (van Scharrenburg, 2019). Chain CH11 (burger chain) and CH 12 (fried chicken) were researched by (Niartika, 2019). They are both international chains.

For each chain four types of analysis were done: (1) packaging and service ware for each food or drink item on the menu of the fast food chain; (2) the observed quantities of packaging and service ware provided to customers averaged over the hourly observation(s) per fast food location; (3) the projected yearly packaging and service ware footprint for the observed fast food locations; (4) projected yearly packaging and service ware footprint for the observed fast food locations to include all locations of the ten fast food chains within Semarang. For each chain, a mapping was made of the locations of their restaurants through Google Maps, see Figure 1.

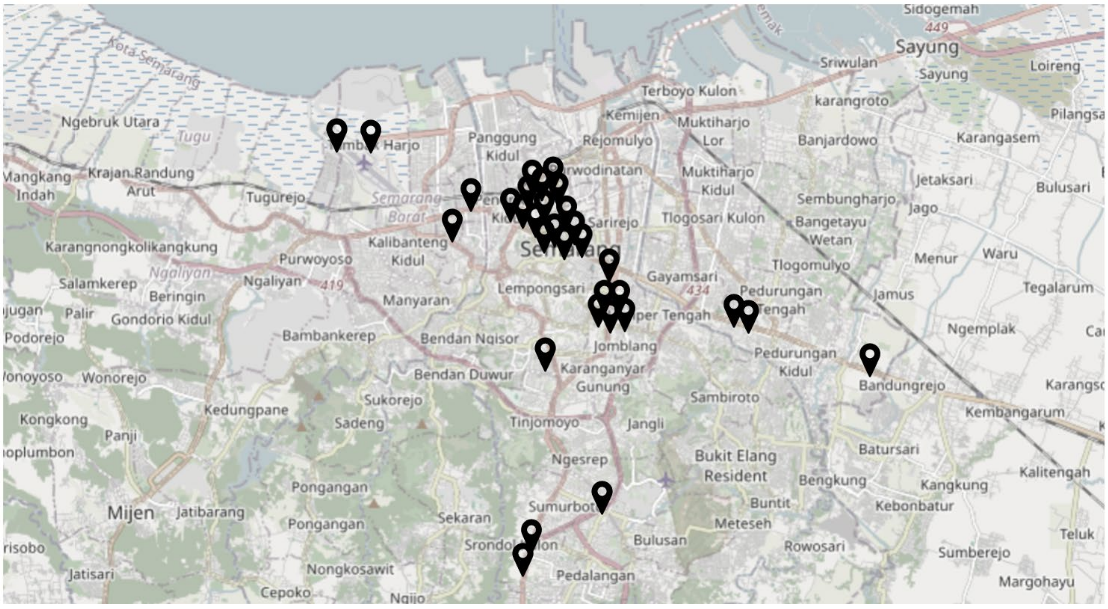


Figure 1. Mapping of fast food restaurant locations in Semarang, Indonesia (Source: based on © OpenStreetMap contributors, ODbL)

In total 36 locations of these restaurants were visited. The selection of the locations to be included in the observational studies was based on the feasibility of observation (for example an accurate view of the counter) as well as the proximity of the different fast food chain locations to each other. Google Popular Times is a function of Google Maps, in which Google uses aggregated and anonymized data from users who have opted into Google Location History to show popular times, wait times and visit duration for certain businesses, including fast food restaurants. Google Popular Times shows how busy the location typically is during different times of the day. Popular Times data are based on the average popularity over the last several weeks.

The fast food chains CH1 to 10 produce approximately 180 ton of packaging and service ware per year. There is a large difference between the chain with the largest packaging and service ware footprint (CH3) and the one with the smallest footprint (CH9) (Figure 2). The difference between the two is 55 ton per year. The international chains (1-5) represent 139 ton of the total, which is 82.3%. If paper (PAP) is not included in the analysis, this leaves a total of 163.7 ton of plastic packaging and service ware per year. Chain CH3 represents the largest footprint (48.5 ton). In this case, the international chains represent majority of the total packaging volume. CH11 generates 2550 plastic waste annually, while CH12 generates 1500 kg plastic waste per year. Packaging and service ware waste in CH11 and CH12 is dominated with non-alcoholic beverages category (Niartika, 2019).

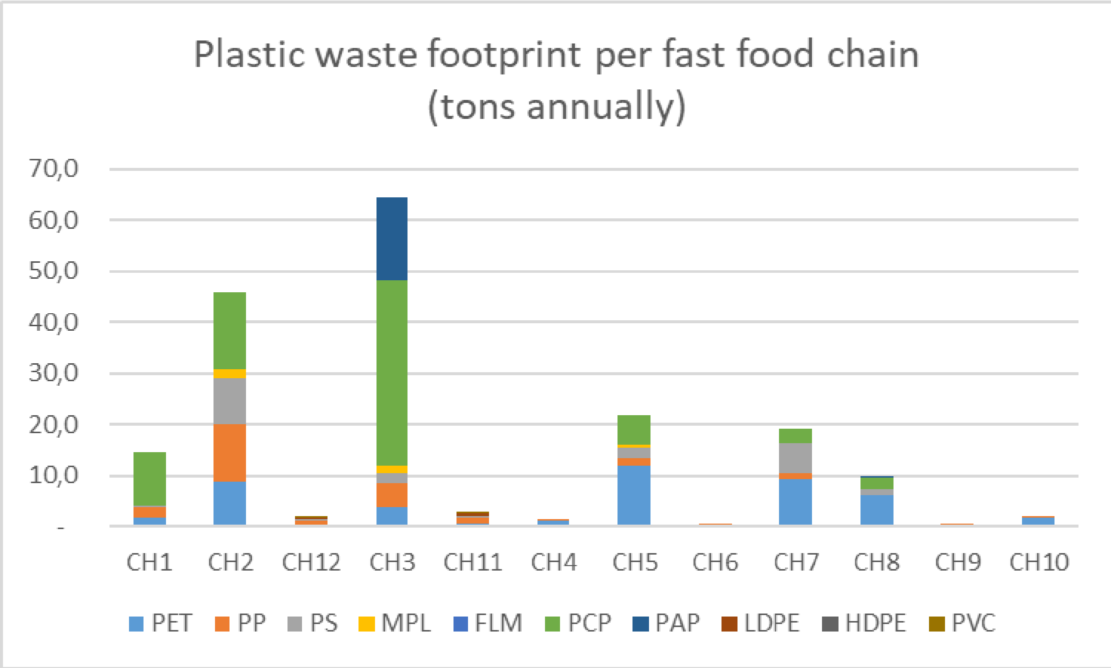


Figure 2. Annual total packaging and service ware plastic footprint (in ton) for all locations of the ten fast food chains in Semarang, calculated by averaging the Google Popular Times (GPT) and Average Hour (AVH) methodology (source: based on Nirakirta, 2019; van Scharrenburg, 2019)

CH4, CH6, CH9 and CH 10 use little packaging and service ware but serve their food on a plate and customers get cutlery. This is not thrown away but cleaned for reuse, usually in a dishwasher. Face value, one could conclude that this is more environment friendly. However, dish washers use energy and water and contribute to other emissions such as CO2. For example, all outlets of CH11 and CH12 contributed carbon footprint as much as 101 tons CO2 eq. annually from single use plastic packaging alone (Niartika, 2019). The amount of carbon footprint depends on the types of dishes, serving size, types of packaging provided by fast food chains and number of visitors. So assessing the environmental impact should be done with care.

MITIGATING ENVIRONMENTAL IMPACTS: FIVE "R" SCENARIO'S

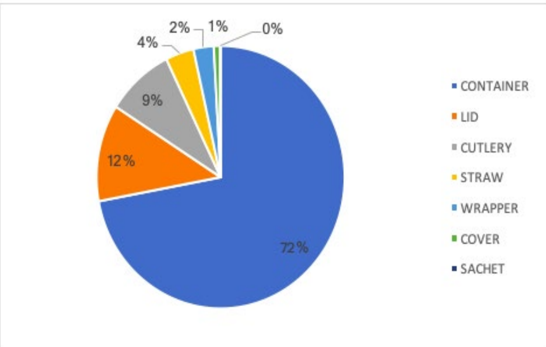
In pursuing large changes needed to deal with growing waste volumes we run into a number of issues that this study aims to provide insight into. First, in order to really tackle the problem more insights and hard data on production, use and end-of-life stage are needed to balance trade-offs. Second, assessing and improving environmental impacts requires careful consideration. Footprinting is a useful tool to identify and help address the potential trade-offs and burden-shifting that can arise when developing and implementing "R" options. The often limiting resources and infrastructure make us also consider 'lower' options such as waste-to-energy. In this section we will analyse 5 scenario's based on the "Rs" reduce, renew, reuse, recycle and recover (waste-to-energy). Both volumes of waste (plastic footprint) as well as the footprint will be compared to the base case: packaging and service ware. Also other issues will be taken into account when discussing feasibility of R options. Note that different studies are presented in this paper (most importantly Bintari, 2019, Niakirta, 2019, van Scharrenburg, 2019 and Senviczki, 2021) with minor differences in methods. For the renew scenario we did not study the footprints as there are arguments to exclude this option upfront. Table 1 summarizes this.

Table 1. Methods applied to 5R scenario's

#	Scenario	Plastic footprint	Carbon footprint
1	Reduce	Yes (Chain 11 and Chain 12)	No
2	Renew biodegradable	No (other arguments)	No (other arguments)
3	Reuse with renewed design	Yes (applied to all chains)	Yes (applied to all chains)
4	Recycle	Yes (applied to all chains)	Yes (applied to all chains)
5	Energy recovery	Yes (applied to all chains)	Yes (applied to all chains)

REDUCE SCENARIO

Reduction of packaging and service ware (plastic) waste generated by the fast food industry can be instigated by focusing only on the most important polymers in plastic-containing items. In this case, information on the proportion of plastic wastes based on polymer types (2). Weight proportion of plastic-containing items generated respectively by CH11 and CH12 fast food chain restaurants in Semarang are displayed in Figure 3. Based on weight proportion of plastic wastes from both fast food chain restaurants three polymer types should be prioritized in the reduction effort. PP, PCP and PET.



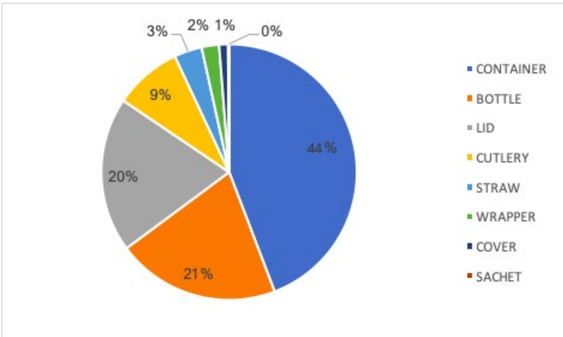


Figure 3. Proportion (weight) plastic waste generated at CH11 and CH12 based on plastic-containing packaging and service ware items (Source: Niartika, 2019).

In term of weight proportion there is a difference between the two fast food chain restaurants. Figure 3 shows that at CH11 restaurant most plastic waste comes from container (72%), lid (12%) and cutlery (9%) and straw (4%). At CH12 restaurant container, bottle, lid and cutlery contribute 44%, 21%, 20% and 9% of plastic waste, respectively. It is assumed in the calculations that environmental impacts are linear in volume. Hence, the environmental impacts of the base line scenario in Figure 4 can be reduced propositionally with volume reduction.

It is interesting to observe that straw represents a relatively small proportion of plastic waste generation at both fast food chain restaurant, i.e. 4% (CH11) and 3% (CH12). The "no plastic straw" campaign has been launched by CH12 in Indonesia since 2016 (OceanView, 2021). The message of this campaign is strong , but in terms of volume it will not tackle the most contributing source of plastic waste generated by fast food chain restaurants. However, if the exclusion of straw is combined with the no-cup lid practice at the fast food restaurants the impact will be much more substantial. It might reduce the weight of packaging and service ware waste wastes by 16% and 23%, respectively for CH11 and CH12. Another benefit is that there are no drawbacks to this reduction scenario.

RENEW SCENARIO: BIODEGRADABLE

For the Semarang fast food packaging and service ware case, Niartika, (2019) recommends PLA material for the future but provides no hard data. Therefore we rely on general studies to assess its feasibility.

To reduce carbon dioxide emission released from the used plastic the replacement of material of which packaging and service ware is made is assumed to be a solution. Yet, replacing one disposable product (e.g. made of plastic) with another disposable product, made of different material (e.g. paper, biodegradable plastic) may fix one problem but perhaps generate other issues. Further, to avoid burden shifting between the environmental and the social dimension, it is important to support manufacturers of single-use products to shift their focus towards the production of more circular and sustainable commodities (UNEP, 2023).

Biodegradable and compostable products, also called bio-based material or bioplastics, are often seen as an alternative to fossil fuel-based plastics. However, these materials can be just as harmful to the environment since they do not biodegrade in the natural environment (UNEP, 2018). These "bio-degradable" plastics break down completely only if exposed to prolonged high temperatures above 50°C, far from usual environmental conditions, especially in our oceans (UNEP, 2016). So also the so called bioplastics, made from renewable resources, for example corn starch or sugarcane, do not automatically biodegrade. Therefore, at the time of research the state of technology for this scenario is not feasible. Therefore we studied an alternative reuse scenario including re-design.

REUSE SCENARIO WITH RENEWED DESIGN

The study by Senviczki (2021) considers a simplified reusable plastic (PP) container for food and for drinks, including its supply chain, shown in Figure 4. A high rate of return can be assumed because the system would operate with a deposit.

Figure 4. Reusable container (Source: ReCircle.ch)

Reuse is optimized to a maximum of 43 loops. Once reuse is no longer possible, in this scenario, recycling is applied. One can also choose to avoid reuse and recycle right away. In both cases the plastic footprint is almost reduced to zero. Figure 5 presents the carbon dioxide emissions in kg for the different scenarios compared to base case . The chart also shows the contribution of different life cycle stages.

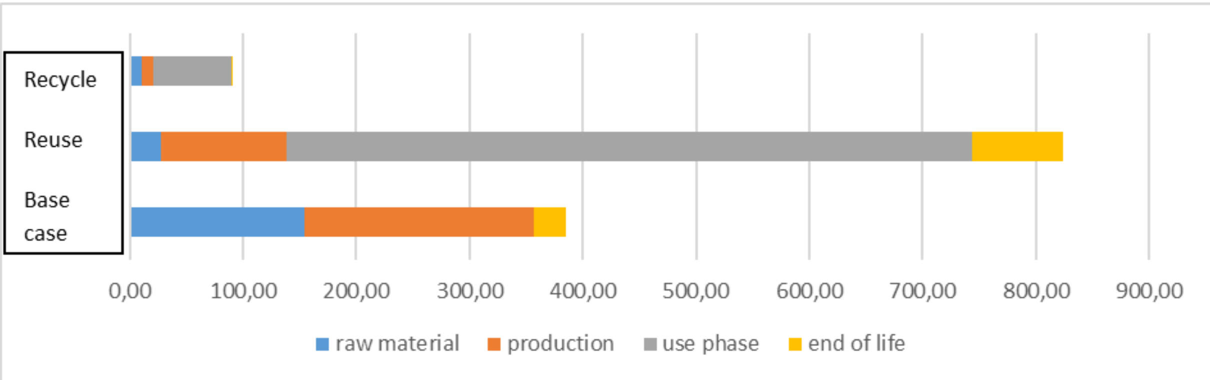


Figure 5. CO2 emissions per functional unit [kg]

Reuse plastic bowl has the highest CO2 emission per functional unit. Its use phase is the main contributor to the CO2 emission due to cleaning/dish washing. Recycling has less CO2 emission associated with use phase. The CO2 emission of the whole life cycle is calculated by the model. In case of the Reuse scenarios the numbers have been divided by the number of reuse loops. Thus, the more time it is used the less emissions associated with production phase will be found per functional unit.

In case of base case scenario the CO2 emission associated with one plastic bowl is the CO2 emission of one functional unit in base case scenario. Its weight is only 6% (0,01059 kg of the RFC's weight (0,186kg), but the production method is the same. CO2 emission is 4.8 times less in case of recycling FC compared to single use one. We investigate the recycling scenario in more detail in the next paragraph.

RECYCLING SCENARIO

Recycling is a viable option in dealing with plastic waste, because of two reasons. First, it has been part of the waste management mandated to municipal governments, and second, the existence of a network of actors involved in recycling businesses. In Indonesia, all municipal governments have to provide waste management services to their citizens in two forms, i.e. waste reduction and waste handling (Law No. 18 of 2008 on Waste Management). Out of 23% unmanaged waste (Bintari, 2019), only 7.5% of waste were recycled. However, Semarang has set a target that by 2025 30% of the waste will be recycled. It means that the city has to increase its recycling capacity up by 4.5% each year. So far there are 198 so called waste banks in 120 kelurahan (villages) across the city of Semarang. Waste Bank is a concept of collecting and segregating solid waste that involves systems similar to banking systems, but what is saved is not money but waste. Savers who are also called customers have a savings book and can borrow money that will later be returned with solid waste worth the money borrowed. Waste deposited by the customer will be weighed and valued with a sum of money, the waste will later be sold at factories or recycling agents or it can also be handed over to local upcycling agents for processing.

A study by Bintari (2019) revealed that 53 active waste banks collected recyclable wastes from 7,105 households weighing about 208 tons/year. Three main components of recyclable wastes dealt by the waste banks are paper (60%), plastic (24%) and cans (5%).

According to Senviczki (2021), a higher recycling rate helps reducing waste and reduces demand for energy and virgin materials (PP based design of container). This leads to lower carbon emissions as Figure 5 shows in the previous paragraph. Importantly, due to contamination post customer plastic products cannot be recycled into the same product for the same food related purposes as there are strict regulations. To enjoy the benefits of recycling, alternative markets must be found. The recycled PP plastic could substitute virgin material when producing plastic crates, pallets, or other non-food related products. For the non-recyclables we need to study a fifth scenario based on Recovery. This is better known as waste to energy.

RECOVER: WASTE-TO-ENERGY SCENARIO

Direct conversion of bulk waste to energy is also considered attractive by cities for contaminated waste. Semarang has planned to implement waste-to-energy (WtE) technology in facing the acute shortage of land fill. The existing final disposal site at Jatibarang can no longer support the city's waste disposal. It is projected that the Jatibarang landfill can only serve the city until the end of 2021 due to over-capacity (Adipradana, 2020). The installed capacity of the WtE in Semarang is 1000 tons of waste per day which will lead to 15-18 mega-watts electricity. The total waste available at Jatibarang is 978 tons per day which is very close to the WtE capacity. The potential conflict between waste-to-energy project and the existing waste recycling value chain is predictable, especially with regard to plastic recycle. Bulk conversion of waste to energy seems very practical but it might endanger the existing recyclable waste value chains and their actors. A simulation study by Bintari (2020) showed that exclusion of 25 to 75% of certain recycleable waste, i.e. plastics (PET, HDPE/LDPE), glass, metal and paper will not reduce the aggregate calorific value per kg waste. However, the exclusion will reduce the total calorific value of the waste up to 15.5%.Waste-to-energy has relatively low environmental impact. ed), Although it does not reduce demand for virgin materials, waste volumes are reduced. In case 10% less recycling is applied in favour of W-t-E only 0.8% more carbon emission result Senviczki (2021). So for non-recyclables this is a good alternative.

Nevertheless, concerns about pollution by WtE especially related to the reduced air quality and ash toxicity have still been around. The WtE technology is therefore disputed in some countries (Christensen et al., 2015). Refusal toward WtE facilities is usually related to environmental justice issue, particularly the unequal distribution of environmental burdens, e.g. pollution. In this case the poorest areas of the town are considered as the preferred sites leading to NIMBY (Not In My Backyard) protests. Dong et al. (2019) have identified key factors determining the potential environmental impacts of four WtE technologies, namely the incineration, pyrolysis, gasification, and gasification coupled with ash melting; and found that the overall ranking of different WtE systems is strongly dependent on operating conditions, such as effectiveness of the air pollution control process, utilization pathway of pyrolysis char, and to a lesser extent, bottom ash management – i.e. landfill or recycling. Moreover, climate and seasonal variations, especially the level of precipitation, could affect the quality and quantity of waste to a reasonable extent. The quality and quantity of waste will significantly affect the WtE process (Tun et al., 2020).

Among the available low carbon technologies, WtE can be regarded as an alternative that reduces greenhouse gases (GHGs) emission. Lifecycle wise, most of conventional low-carbon technologies are slightly positive in terms of GHGs emissions since energy is needed to make and operate the facilities. WtE prevents landfill methane (CH4) emissions while other renewable technologies still emit it (Fink et al., 2013). A determinant of the WtE sustainability is its potential contributions to climate change mitigation, i.e. CO2-emissions and savings. The efficiency of energy recovery of the WtE facility is therefore a very important factor (Christensen et al., 2015).

A simulation study in Malaysia by Tan et al. (2014) on WtE with 1000 tons/day of municipal solid waste (MSW) input revealed that incineration produced

480 MWh/day of electricity and avoid an emission of 2250 tons CO2/day carbon by fossil fuel replacement as compared to the base case. Life cycle assessment studies showed consistent results, i.e. MSW combustion is a better option than landfill disposal in terms of net energy impacts and CO2-equivalent emissions.

The WtE technology is disputed in some countries (Christensen et al., 2015). Despite of the pros and cons, actually the existing WtE facilities are much more superior than that of the 1970s and 80s in terms of the air pollution (Fink et al., 2013). This fact obviously still demands a more intensive public dissemination.

CONCLUSIONS AND RECOMMENDATIONS

Our studies sketch a very diverse picture of environmental impacts of single - and multi-use packaging in the fast food industry in Semarang. We have evaluated five circular scenario's, showing that environmental impacts are not only divers and that some of these scenarios are not even sustainable. Alternatives to single-use should therefore be carefully thought of. Table 2 summarizes the pros and cons of 5Rs studied. We will elaborate below.

Table 2. Findings of the five "R" scenarios

Scenario	Positive	Concerns
Reduce	Marketing message, no harm done in any case	Limited impact in terms of footprints
Reuse	Reduction plastic footprint, less virgin material needed	Poor carbon footprint results
Renew	May enhance closed loop reuse and recycling (PP)	Biodegradable not yet possible
Recycle	Plastic footprint reduced, less virgin material needed, good carbon footprint results, infrastructure potentially available on Java	Open loop applications (alternative markets), requires high volume collection
Waste-to-energy	Plastic footprint results, fairly good footprint results, infrastructure potentially available on Java	Does not reduce need for virgin materials, latest technology needed, requires high volume collection

Based on the results we conclude that a combination of reduction of problematic and unneeded plastic, recycling and waste-to-energy are most feasible at the moment in the case of Semarang. Renewing design may increase quality of recycling in a closed loop system. The reduce scenario is important since the production of plastic is a significant contributor to the environmental footprint. Moreover, some products are unnecessary and easy to avoid, like straws. Also, the marketing impact is not to be underestimated. However, a significant impact can only be achieved in combination with the renew scenario, meaning hazardous and difficult to recycle plastics should be replaced. The reuse scenario, that keeps a product in the economy for longer, might have some other negative impacts to consider.

Recyclable plastic waste has been attracting various actors to get involve in its value chain. In Semarang the network of actors in plastic recycling activities can be seen in Figure 6.

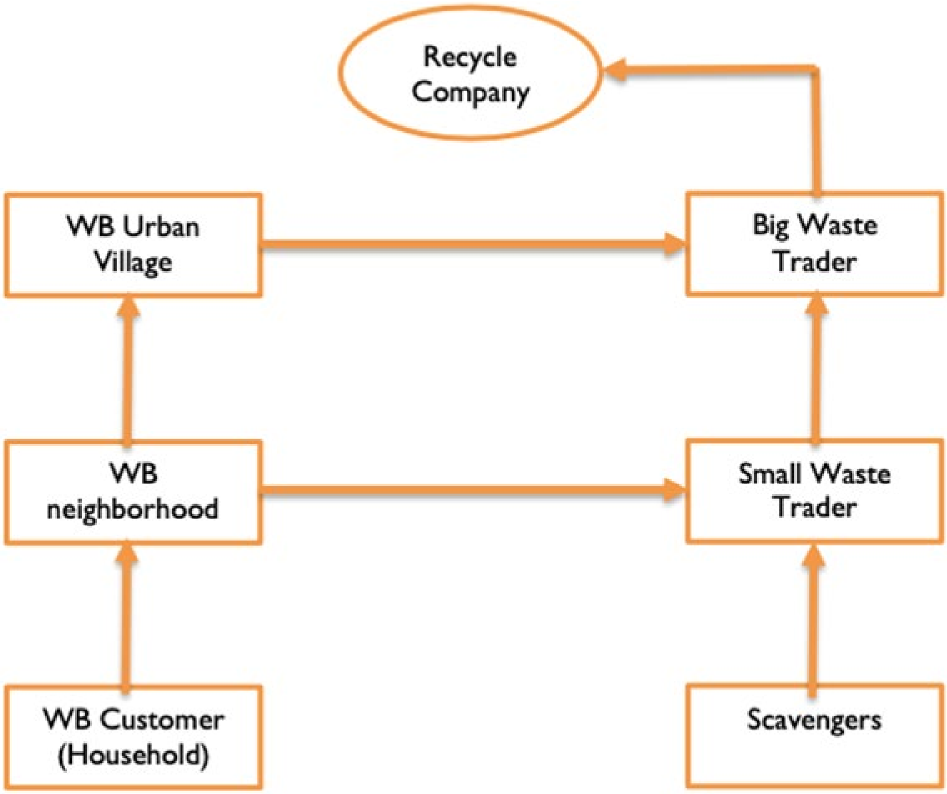


Figure 6. Actors in Waste Recycling Value Chain (Bintari, 2020)

(WB = WASTE BANK)

The recycle activity can also enhanced by the extended producer responsibility (EPR) initiatives (Widianarko, 2021). There are two categories of recyclable plastic waste which have different value. The most valuable one is PET bottle which is considered to have a high economic value and well absorbed by the recycle market. Therefore this type of plastic waste has been 60% collected and recycled. On the other hand, multilayer plastic from packaging waste is light and cheap. It is therefore not attractive to the recycle market. There are examples of EPR initiatives focusing on PET bottle in Indonesia which are quite successful. One of them is NiatMurni, a collaboration to take-back PET bottle between waste banks, beverage industry and an online ride hailing service called GOJEK (Bintari, 2019). A notable effort to deal with Multilayer Plastic is initiated by Mari Food a local company in Semarang. This company has been promoting Eco-Bricks which is basically inserting multilayer plastic waste into a PET bottle. The company's training programs embraces schools, NGOs, public & private agencies (Bintari, 2019).

Despite of the concerns, the most recent WtE facilities are much more superior compared to that of the 1970s and 80s in terms of the air pollution (Fink et al., 2013). This fact obviously still demands a more intensive public dissemination. Combined with recycling, it is probably the most realistic solution short term. Unlike for example smart phones, we expect that technology leaps are not likely to happen. In other words, one should start with the "R" scenario's lower in the ranking (some will argue end-of-pipe) and from there work towards more high level circular scenario's. Recycling and WtE require economies of scale in order to be viable. Also they compete for waste and hence dual implementation requires a good collection system.Finally, it is an illusion that plastic (packaging) will completely disappear. We should choose future solutions based on the following criteria. (i) Apply reduce, reuse, repair or recycle as a first priority; (ii) if packaging is not reusable or recyclable, or actively hampers the recycling process then renew or repurpose; (iii) improve collection systems in terms of coverage and containment to support all R options and prevent leakages. (iv) Manufacturing of plastics packaging requires hazardous chemicals that pose a significant risk to human health or the environment, also refuse or renew apply here. (v) The options refurbishing and remanufacturing do not apply to plastics (in) packaging waste today and we do not expect this will change.

WIDER IMPACT AND FUTURE RESEARCH

Sustainable development goal 12 of UN, addressing responsible consumption and production in target 12.5 "focus on waste generation reduction through prevention, reduction, recycling and reuse". SDG 14 is addressing the reduction of marine litter via the focus on waste generation reduction (target 14.1) and on sustainable management (target 14.2) (SDG14). The Basel, Rotterdam and Stockholm conventions share the common objective of protecting human health and the environment from waste. It is interesting to roll out these solutions in other parts of Asia.

Further research on perfect circularity in conjunction with issues on (clean) energy and water consumption. As a first step however, changing product composition (type of plastics) should be the core of research to improve recyclability, energy efficiency and biodegradability. LCA including volumes of unmanaged waste and virgin materials needed should be applied in future research.

ABBREVIATIONS

FLM, Plastic Film; MPL, Metalized Plastic; PAP, Paper; PCP, Plastic Coated Paper; PET, Polyethylene Terephthalate; PP, Polystyrene; PS, Polypropylene.

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DATA STATEMENT

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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