4. DISCUSSION

4.1. Single Use Plastic Waste Generation by Amount

Table 3 shows the combination of the two convenient stores (IH and IP) can produce nearly 1,000 items of SUP waste per day which is only produced from dine in consumers. The fact that IP and IH generated 635 and 300 SUP waste items per day, proves that there is a change of lifestyle. Nowadays people tend to go to the convenience store for having their meals. The development of ready to eat food will continue to grow, and must be supported by the choice of environmentally friendly packaging materials. In one year, more than 100,000 and 200,000 items of SUP waste are produced by IH and IP, respectively.

More SUP wastes were produced during the weekend 2.68% and 50.53%, respectively for IP and IH. IP produced twice as much as SUP wastes that of IH in term of amount. This results directly proportional to Alfagi et al., (2015), the number of fast food sales was higher at the weekend. This is stated by the increasing of 15.85% of waste produced. Saturday contributed to the highest amount of waste in a week, followed by Friday. Similar amount of waste are generated between Sunday and other weekdays. Meanwhile, Monday produced the lowest amount of waste. Fifty five percent of the total waste generated was inorganic, such as SUP food cutlery.

4.2. Single Use Plastic Waste Generation by Weight

Table 4 present the weight (kg) of SUP waste generated per year, based on each type of polymer, weekend and weekdays, and types of IR. PET is the most generated SUP waste i.e., more than 2,500 and 1,200 kg/year (72% of the total polymer) for IP and IH, respectively. PS and HDPE are the second and third largest generated, i.e., 365 and 282 kg/year, 153 and 149 kg/year, for IP and IH, respectively. The percentage of PS and HDPE is only 8-11% and 7-8% of the total polymer. PP and LDPE are the two least produced polymers, only 111 and 84 kg/year and 57 and 31 kg/year.

In term of global polymer used in 2015, types of polymer contributing more to the SUP waste presented as the following order, i.e., LDPE or LLDPE (27.6%), PET (20.7%), HDPE (19%), PP (16.8%), PS (PS 4.7%), and PVC (1.8%) (Rabnawaz, Wyman, Auras, 2017). Major difference between the results obtained and the reference lies in the percentage of LDPE. It is suspected that the percentage of polymer use in the reference based on general packaging use (not specific as food packaging). The use of plastic bags and flexible films is directly proportional to the amount of LDPE used (rarely use in dine in consumers).

IP produced twice as much as SUP wastes that of IH in term of weight. The annual amount of SUP waste generated reach more than 3,500 and 1,700 kg for IP and IH, respectively. It is related to the design of convenience store; IP located in the center of city and dominated by ready to eat (RTE) food products and beverages. The existence of coffee shops at IP (cafe point) increased the amount of SUP waste, due to the use of packaging or container, and cutlery. Various snacks and beverages are more available at IP, while in IH which is a transition between general IR and IP, the products sold is a combination of both.

More SUP wastes were produced during the weekend 0.4% and 42.9%, respectively for IP and IH. IP is designed for gathering places and an unexpected event often occurs both in weekdays or weekend. Grouping Friday as weekdays influences the amount SUP waste, particularly at Friday evening.

4.3. SUP Waste Generation by Food Category

Various products sold at convenience stores then grouped into 11 modified food category based on Auestad et al., (2015) and Rhodes, Adler, John, & Moshfegh (2017). The 11 food categories consist of (1), breads, grains, cereal product; (2), coffee (others-nonalcoholic beverages); (3), energy drink (others-nonalcoholic beverages); (4), fruit; (5), juice (others-nonalcoholic beverages); (6), milk, and other dairy products; (7), mixed dishes; (8), snack, and sweet; (9), soft drink (others-nonalcoholic beverages); (10), tea (others-nonalcoholic beverages); and (11), water (others-nonalcoholic beverages).

Based on the 11 food categories, 6 of them are gathered as “non-alcoholic beverages”, i.e., coffee, energy drink, juice, soft drink, tea, and water. The weight of SUP waste contributed by them reached more than 3,000 kg/year and 1,500 kg/year or (85% and 90% of the total waste) for IP and IH, respectively. Interestingly, the two major categories of “non-alcoholic beverages”, i.e., water and tea accounted for more than 1,860 and 839 kg/year or (±50% of the total waste) for IP and IH, respectively.

Water and tea are the major contributors to PET, HDPE, and PVC in both IP and IH. PET polymers has excellent thermo-mechanical properties that are critical for food packaging application, i.e., PET has a Tm and Tg of 245 and 73℃, respectively, that allow to withstand in elevated temperatures. The addition of nucleating agent accelerates the crystallization process and formed spherulites. The translucent PET-based products are formed due to the existence of micron-sized spherulites which readily scatter light. These crystallized PETs are useful for high temperature food container, such as microwavable food containers. PET as a crystalline polymer provides excellent barrier properties for CO_2, water vapor, and oxygen transmission. So that, PET serves an excellent properties for sealed container and beverages bottles. PET container application suitable for UV-sensitive food products, since it block UV-A (400-315 nm), UV B (315-280 nm), and UV-C (280-100 nm) (Rabnawaz, Wyman, Auras, 2017).

HDPE has outstanding mechanical properties as well as excellent water barrier properties and much applied as caps for bottles, food container, and flexible packaging film for various snack. Because of PVC favorable properties, such as low production cost, highly acid and base tolerant, transparent, and higher gas barrier properties, it has been made into a large number of plastic products with different hardness based on the proportion of modulation. Current used of PVC in beverages industry is for wrapping or label packaging film (Kao, 2012; Rabnawaz, Wyman, Auras, 2017).

The main contributor to LDPE producers in IP is fruit based category, and for IH is milk, and other dairy products. LDPE is soft and has excellent flexibility, it is widely used as squeezable containers and flexible films (Rabnawaz, Wyman, Auras, 2017; Siddique et al., 2008). Bread and various types of grains are the main contributors to PP and PS in both IP and IH. However, PS at IH also contributed by sliced fruit and mixed dishes packaging.

In food packaging industry, PP is major used as flexible film because PP is odorless, acid and base resistant, and tasteless (Kao, 2012). PP has a melting temperature and glass transition temperature of 160-175 and (-10)℃; Young's modulus 1.1-1.5 GPA; tensile strength 31-42 MPa; elongation at breaking point 400%; WVTR x 10^{-12} 1.16-6.94 kg.m/m^2.s ; and oxygen permeability coefficient x 10^{-18} 1.96-2.94, that it's suitable as a flexible film (Rabnawaz, Wyman, Auras, 2017). PS is cheap, having an excellent gas barrier properties, and high acid and alkaline tolerant. It is widely use to form disposable tableware (plates, cups, and others food cutlery), instant noodle containers, lunch boxes, and bowls (Kao, 2012).

Coffee is an interesting category since its packaging includes all six types of polymer. In a lesser extent, energy drinks, juices, milk, and tea (others-nonalcoholic beverages) are packaged with five types of polymers. Snacks and sweets contributed the least SUP waste, limited to PET and PP

4.4. Carbon Footprint (CF) of SUP Waste

Carbon footprint (CF) is a measure of greenhouse gas (GHG) emissions associated with a product or activities (Roibás et al., 2018). Based on equation 2, the weight of the polymer (kg), total number of dine in visitors, conversion coefficient for each type of polymer may influences the CF produced. In terms of conversion coefficient value, types of polymer contributing higher CF value presented as the following order, i.e., PS, PET, PVC, HDPE, LDPE, and PP. Lower CF produces by lower polymer weight and conversion coefficient, and higher number of individual dine in, and vice versa.

The largest CF contributor at IP and IH is PET, PS, HDPE, PVC, PP, and the smallest is LDPE. This order is directly proportional to the order of the weight (kg) of SUP waste generated (Table 4). PET covers 76.6% and 77.3%; PS covers11.8% and 10.4%; HDPE covers 4.9% and 5.4%, PVC covers 3.4% and 3.8%, PP covers 1.7% and 1.9%, and LDPE covers 1.4% and 1.1%of the total CF for IP and IH, respectively.

Weekend results in a higher CF value for IP. In contrast, IH CF values are higher during weekdays. Lower CF produced in weekend at IH is suspected due to higher number of visitors, but lower amount of SUP waste generation (look at equation 2). The number of IH visitors is 223 and 329 peoples per day for weekdays and weekend, respectively. In addition, IP produces 38.9% (5.306 kg CO_2 eq) higher CF than IH. This result is directly proportional to the weight of SUP waste generated, i.e., more SUP wastes were produced during the weekend.

Convenience stores CF, defined as the sum of SUP waste CF from whole IP and IH. IP and IH stores generated more than 8,500 and 4,000 kg CO_2 eq per year. Based on Google in 2019, there are 9 IP and 90 IP, and 8 IH and 92 IH located in Semarang and Indonesia, respectively. It is estimated that IR convenience stores in Semarang and Indonesia emit CF approaching 109,000 kg CO_2 eq per year and 1,100,000 kg CO_2 eq per year, respectively. Indonesia CF produced in 2017 reached 0.51 Gt CO_2 eq which consisted of electricity and heat production (25%), agriculture, forestry and other land use (24%), industry (21%), transport (14%), other energy (9.6%), and buildings (6.4%) (Eickemeier et al., 2014; Olivier, 2018). Indonesia food carbon index 2018 explains the CF produced by animal and non-animal based food is 181.18 and 125.94 kg CO_2 eq per year per individual, respectively. Based on *badan pusat statistik* (BPS), the total population of Indonesia in 2017 was 255.461.700 person. The estimation of CF produced from food categories in Indonesia reaches 7.85×10^{10} kg CO_2 eq per year. Food packaging CF generated by IP and IH stores only covers 0.01% of the total CF generated by food category.

4.5. Carbon Footprint (CF) of SUP Waste by Food Category

Based on the eleven food category, beverage products produce higher CF values. Water, tea, and coffee are the three main contributors to CF, i.e., 67.2 % and 72.9% or (more than 12,700 and 9,900 kg CO_2 eq) of the total CF generated by IP and IH, respectively. All three products produce CF values 28% higher in IP (directly proportional to the weight of the waste). Bread, grains, and cereal product produce contribute 6.1% and 3.3% of the total CF for IP and IH, respectively. Milk and other dairy products contribute to 3.7% and 3%; fruit 2.7% and 1%; mixed dishes 2.4% and 1.5%; snack and sweet less than 1% of the total CF for IP and IH, respectively. In addition, IP produced twice as higher as CF values that of IH.

The CF value obtained is directly proportional to the results in Tables 5 and 6. It can be concluded that the weight of the polymer (Pi) is the main factor influencing the value of CF in this research. The similarity of the polymer order pattern that produces the highest amount (kg) of SUP waste and CF value causes the conversion factor of the polymer (Cci) to be less influential. The same number of dine in individuals (n) also has no effect (look at equation 2).

4.6. Solution from Food Technology Perspective

Global greenhouse gasses or GHG emissions are predicted to grow more than 50% from 2010-2050, with an acute risk of a two-degree increase in average of global temperature (OECD, 2012). The human population continues to grow, with a forecast for 2050 about ±9.1 billion people; this would require an increase in food production and it’s packaging close to 70%. Worldwide production of polymers in 2015 reached more than 407 million tons, and ±44% of the polymer produced is used in the packaging sectors (Rabnawaz, Wyman, Auras, 2017). Special attention regarding food packaging materials, especially plastic packaging materials, is a global issue.

Based on the 11 food categories, beverages products contribute to the highest CF, especially for water, tea, and coffee (instant coffee and bottled coffee). To reduce the environmental burden caused by the beverage sector, the solution is to create more environmentally friendly system. Comparative LCA assessment of aseptic packaging and hot filling systems show that the hot filling systems has a higher impact because of the higher energy requirement during the heating and cooling phases, and the energy used cannot be recovered. It is interesting that aseptic packaging require higher electricity but less steam. Aseptic packaging system has a lower weight compared to the PET bottles designed for hot filling system (16g and 24g). The distinction in material weight makes a 27% reduction in the impact of aseptic packaging materials. The results conclude that the aseptic packaging systems had a lower impact in all categories assessed (Manfredi & Vignali, 2015).

The current food industry trend is to use lightweight PET bottles. The bottom limits for PET bottles is 20g and 12g for hot filling and non-hot filling bottles, respectively. Weight reduction of 4g PET bottles (24g to 20g) reduces the possibility of ozone depletion by 11% (Manfredi & Vignali, 2015). The weight of PET bottles (2L) for soft drink has decreased from 68 to 51g (about 25%),resulting in savings 206 million pounds of plastic per year (Marsh Kenneth, 2007).

Although petroleum-based polymers offer excellent mechanical properties, they cannot be renewed. Recently, bio-based biodegradable polymers began to widely used, such as poly (lactide) acid (PLA). PLA is synthesized commercially through ROP of lactides. High molecular weight (Mw) PLA obtained by polymerizing lactide in a liquid state to generate low Mw PLA and polymerizing the obtained PLA along with lactide in solid phase to generate high Mw of PLA. Lactides mostly exist as L-lactide isomer along with certain % of D-lactide isomer. As a result, PLA used in the packaging sectors generally contain 92% L-lactide, or more. The mechanical properties of PLA, such as Tm and Tg are influenced by D-isomer content. Increasing the percentage D-isomer decreases crystallinity. The higher D-lactide content (more than 10%), makes PLA completely amorphous (Auras et al., 2005).

Because of its semi-crystalline nature, PLA has excellent O_2 barrier properties (10 times better compared with PP). At elevated temperatures, the O_2 permeability PLA increased due to faster diffusion rate of permeant. However, the O_2 permeability of PLA could decrease with the increasing of water content which might be caused by the water absorbed by PLA filling the site blocking the pathway where O_2 molecules diffuse. PLA is a poor barrier for water vapor (Rabnawaz, Wyman, Auras, 2017). Such matters can be solved by coating or incorporating PLA with hydrophobic material to prevent water contact with starch. PLA coating with 6% w/v TPS foam has been shown to reduce 225% water absorption, and increase density, impact strength, and tensile strength (Bergel, Machado, Marlene, & Santana, 2018).

The incorporation of carbon nanotubes (CNT) and graphene into PLA is a promising nanotechnology approach for the optimization of mechanical and thermal properties. Although nanocomposites are tightly bound in the polymer matrix, their release through cycles is possible. During a strong static migration test, released organic matter and nanoparticles are estimated to be around 0.03 to 0.05 mg/cm^2, where the migrated nanocomposite is 0.006 to 0.011 mg/cm^2. Substances released bellow the migration limit (OEL = 0.10 mg/cm^2) for food packaging material regulated by the EU regulatory documents (Stanislav Kotsilkov, Evgeni Ivanov, 2018).

The best mechanical properties of PLA are presents in 2-10 mol% of the D-lactide isomers. PLA with 6% D-lactide is a rigid material and has a Young's Modulus 2-3 times higher than PP and PHA, i.e., 2.5 Gpa.Thermoplastic PLA compositions can be strengthened by ethylene copolymer which combine glycidyl groups. An oriented film with an increased Young's modulus and tensile strength can be obtained by fusing and extruding PLA (Rabnawaz, Wyman, Auras, 2017).

Oriented PLA (OPLA) and OPLA + 40% recycled content compared by OPS and PET to investigate the suitability of PLA uses in food packaging industry. Exposure to all four types of polymer to strong and weak acid, and vegetable oils show a slight decreased in the performance of these polymer. At the highest temperature, PET has the highest impact resistance, followed by OPLA, OPS, and OPLA+40% recycled content. In term of O_2 barrier properties, PET shows the highest barrier, followed by OPLA, OPLA+40% recycled content, and OPS. It can be conclude that PLA can be used for fresh food packaging (Auras et al., 2005).

PLA is FDA approved for food packaging applications, and is therefore useful for food containers, cutlery, coated paper, and rigid thermoformed containers. Germany McDonald and Dannon were utilize PLA into yoghurts container and cutlery (Rabnawaz, Wyman, Auras, 2017).In terms of CF, PLA generates lower CF than other petroleum based polymer (Gaihong, Shuqiang, Husheng, 2015). Therefore, the use of PLA or other biopolymer can be an alternative to environmental friendly packaging.

The feasibility weight reduction of PLA can be obtained by ultra-thin films or trays. Assuming the symbols w is weight, d is density, T is thickness, E is modulus of materials, the opportunity to reduce weight when using PLA instead of PP trays with similar area and types of products, is as follow:

C. WPLA = WPP

Where C is a coefficient indicating weight reduction

C.TPLA. A. Dpla = TPP. A. Dpp
C TPLA Dpla = TPP. dPP
C = TPP/TPLA dPP/dPLA

Assumption: the tray behave like beam, it could be concluded from the classical engineering bending equation, that the minimum thickness of trays is inversely proportional to the cubic root of the modulus, therefore:

$C = (EPLA/EPP)^{0.33}\ dPP/Dpla$

$C = (2.3)^{0.33} * 0.77 = 1.7$

This predicts that a fiber reinforced PLA may offer up to 70% weight reductions.

On the account of the errors in the assumption, i.e., of a) the fact that the tray is not 100% behave like a beam, b) the increase of the modulus may not be suspected one, c) the density of PLA microfibrils is equal to the one of PLA (Kosior, Limited, & Centre, 2006).

Eco or environmental friendly design of packaging can be obtained by 3R principles, i.e., reduce, reuse, and recycle (Alfagi et al., 2015). Related to reuse or refillable containers for PET and PC bottles, and PP vending cups; the migration of plastic constituents, barrier properties, degradation products of plastic additives, and surface properties were not affected by repeated use. Only the hydrophobicity properties of PP and PC seemed to be influenced by repeated used. PC bottles become less hydrophobic after 15 times used (Jetten & Kruijf, 2002).Recycling aims to divert materials from the waste stream into recovery (4R principles, 3R + recovery) (Marsh Kenneth, 2007). Currently, replacement using more environmental friendly materials (bio-based and biodegradable) become the additional principles to obtained eco-designed (5R principles, 4R + replacement).