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When One Cannot Bypass the Byproducts:

What Countries Produce and Consume Packaging Waste?

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When One Cannot Bypass the Byproducts:

What Countries Produce and Consume Packaging Waste?

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Abstract: While packaging is praised for reducing waste, more especially of food products, packaging waste is a growing concern. Its least recyclable type, plastics waste, is increasingly polluting the marine environment and many developing countries now refuse to take the waste of developed countries. Before responsibility can be established, one has to identify the key producers and consumers. Based on a new and exhaustive dataset, we find that the world's top suppliers of packaging waste are China and Canada but 19.4% of their production is induced by international trade. The consumers that lead to packaging waste are disproportionally located in the USA and they mostly buy food and beverage products. We conclude that international efforts need to assign shared responsibility and promote improvement in packaging recyclability.

One Sentence Summary: We identify the countries and economic sectors responsible for the international production and consumption of (plastic) packaging waste.

Reducing waste, in its many forms, is a central focus for policymakers, advocacy groups, and businesses across the globe. Packaging waste has attracted a lot of interest recently because its impacts on the environment and especially marine life (the "Great Pacific Garbage Patch" (*1*)) are visible and pose a significant challenge to solid waste management efforts (*2*). Other examples are the 24 million plastic bags consumed in Kenya each month of which half ends up in the solid waste stream (*3*). Many developed countries produce even more packaging waste (*4*). While, for many years, developed countries have shipped their recyclable and unrecyclable waste in developing countries so they can meet their recycling targets and reduce domestic landfill, an increasing number of the latter countries are following China and Malaysia in tightening or simply refusing any new waste intake for environmental and health reasons.

Packaging waste refers to the part of the packaging that is thrown away after use, whether it is a single use grocery bag or a wooden pallet that has been used multiple times in the supply-chain (*5*). Packaging waste, by definition, is not recycled so it also includes the residual of items such as glass bottles that have been recycled several times over their lifetime. In response to rising concerns over packaging waste, many local and federal governments are taking action by introducing legislation (*6, 7*) or making pledges to reduce or restrict waste *(53)*, particularly for plastics. At the international level, the March 2019 UN Environment Assembly in Nairobi saw 170 countries pledge to "significantly reduce" the use of throwaway items like plastic bags and plastic straws by 2030 *(54)*. While such efforts are critical for

reducing packaging waste, it is also important to recognize the difficulty associated with avoiding packaging completely. For example, packaging can clearly extend the shelf life of fresh foods and thus help prevent food waste.

Policies targeting packaging waste may also fall short if they singularly focus on consumption. The combination of increasing economic specialization and decreasing transportation costs has led the places of production and consumption to be more decoupled than ever before *(8-10).* Production is now fragmented into a series of specialized processes based on global differences in technology, factor endowment, and factor prices *(11-15).* International trade has therefore led to an increase in the use of packaging, which complicates the task of identifying the responsibility of each individual national government as it requires understanding the role of producers and of consumers *(16)*. The ecological footprint *(17)* and environmentally extended input-output literatures *(18-21)* have both adopted a global system approach to account for the environmental impact associated with production, trade and consumption at the national and international levels. Findings based on these techniques can highlight the extent to which consumption in one country relies on production, and hence waste, in another country. To date, the bulk of the literature has focused on air emissions *(22-27)* and water use *(28, 29)*. Following the contribution of Nakamura and Kondo (*30)*, only a handful of studies have relied on international trade linkages embedded in the input-output framework to highlight waste management problems (*31-33)* and no work focuses specifically on packaging waste.

What countries and commodities/activities generate the most packaging waste?

Based on 2011 data from Exiobase *(5, 34, 35, 55)*, Fig. 1 below shows that China, Canada, Germany and the USA are the top four suppliers *(56)* of packaging waste. Collectively, the four economies generate a staggering 77.7% of the world packaging waste. This value is relatively large compared to the 45.8% of the global economy that they represent *(57)*. Generally, packaging waste is mostly due to domestic consumption. Indeed, on average around the world, exports represent only 20.3% of it. However, this share is at 28% in Canada. The first reason is that Canada's share of export in its gross domestic product reaches 25.7% *(57)*, which is way above where it stands in the USA (8.0%) and China (18.1%). Second, Canada's rich oil and natural gas resources in conjunction with recent shale gas developments help provide the chemical raw materials necessary for the production of virgin plastic resin such as polyethylene, the most popular plastic in the world.

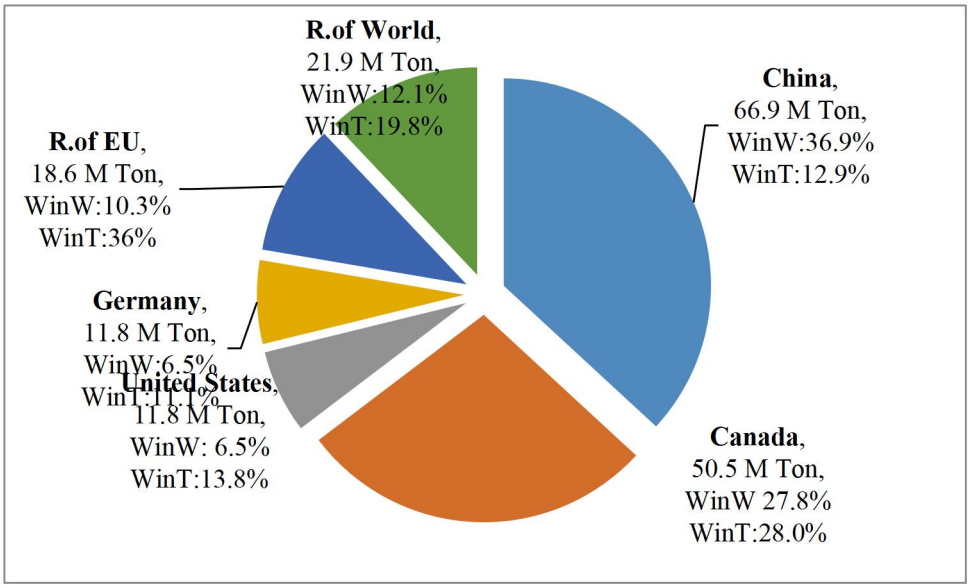

Fig. 1. Total packaging waste supply (M Ton: Million Tons, WinW: Share of the world's waste supplied by country; WinT: Share of export in the supply of waste by country**)**

While the number of activities/commodities that directly require packaging is fairly limited *(34)*, every single sector of the economy requires packaged commodities at some point of its supply-chain linkages. As shown in Figure 2, when all these linkages are accounted for, the commodity that induces the most packaging waste per weight of production is "the manufacture of fish products". These products are usually sealed in plastic wrapping that prevents spoilage from exposure to air or contamination by foreign materials. Yet, each kilogram of manufactured fish requires 7 kg of plastic and 2 kg of paper packaging such as cardboards for delivery to final consumers. Other edible products such as meat, beverages and dairy products require directly large quantities of direct packaging also *(58)*. The second largest group of commodities producing packaging waste is the production and mining of precious metals. Compared to edible products, their need for packaging is indirect as it refers primarily to (international) shipping and it combines a relatively similar share of paper, glass and plastic. Combined together, each kilogram of precious metal requires around 6.8 kg of packaging.

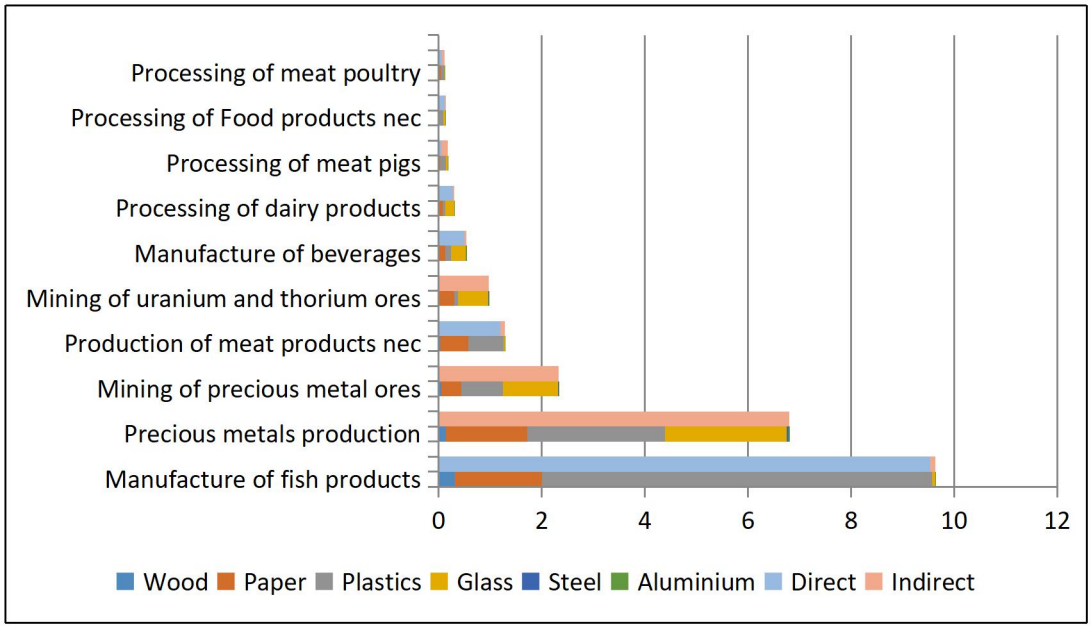

Fig. 2. Top 10 commodities generating packaging waste (kgs of packaging waste per kg of production of the commodity).

When it comes to services (Fig. 3), “Hotels and restaurants” is the largest creator of packaging waste as it transforms food products delivered in plastics and paper into plated meals and sells beverages contained in glass bottles. All materials are used indirectly (they are used directly by the food and beverage manufacturing industry) at a rate of 14.5 grams of packaging wasted per euro of production. “Retail trade services”, the second largest waste producer, relies on a direct use of plastics for the delivery of goods on pallets and offers plastic bags to its customers. It is important to note that the accounting framework we use here attributes the packaging wrapping the products sold in a retail store to the sectors that manufactured such products. It allows us to track the amount of packaging waste each sector produces and avoids us to conclude that households produce the largest amount of packaging waste by regularly discarding the packaging from the goods they purchase.

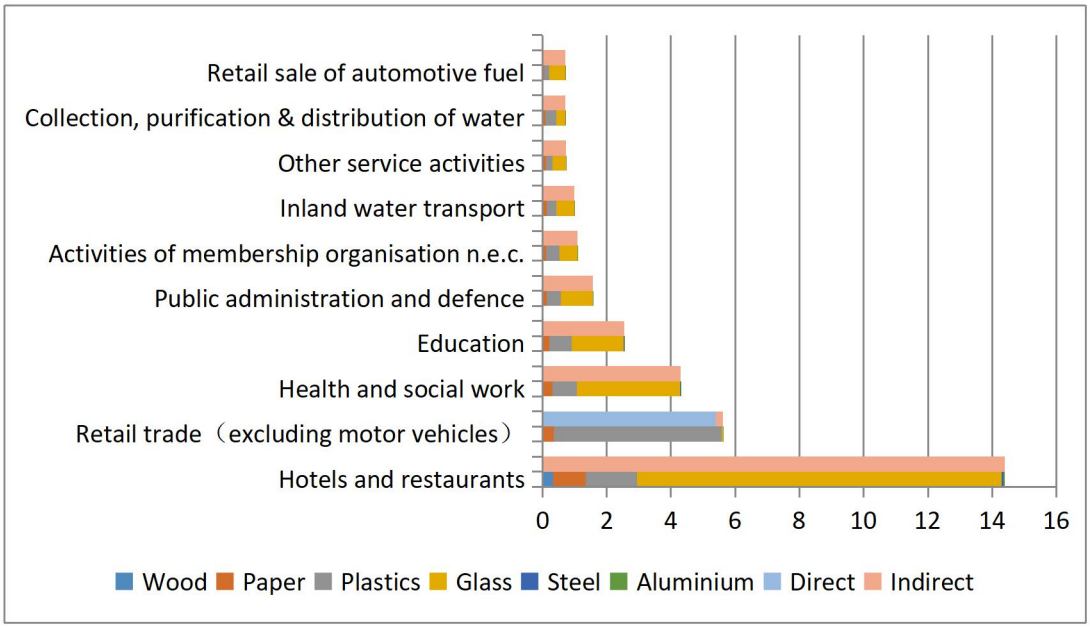

Fig. 3. Top 10 services generating packaging waste (grams of packaging waste per euro of production)

The growing concern with plastic packaging waste

Glass, paper, and plastics constitute the largest shares of the packaging wastes at 48.4%, 34.5% and 15.6% of the total respectively. However, compared with other materials, plastic packaging waste has the lowest recycling rate, even though it differs from one country to the next. For example, the recycling rate for plastics is 14.65% in the U.S. and 46.19% in the U.K. as shown in table 1. While this rate is still higher than the average recycling rate of overall plastic waste (9.1% according to EPA, as shown in table S1), the low recycling rate of this material means that new amounts need to be produced, which leads to new emissions in the atmosphere. Indeed, after aluminum which has a recycling rate double that of plastics, each ton of plastics produced releases an average of 1.93 tons of greenhouse gas emissions in the atmosphere directly and 3.45 tons in total when supply-chain linkages are included *(59)*. Faced with the huge environmental threat from plastic waste, an increasing number of countries have proposed strategies to improve its low recycling rate *(36, 37, 53)*. For instance, in 2018, the European Commission released its European Strategy for Plastics aiming at all plastic packaging on the EU market to be recyclable by 2030. In the absence of a national strategy, various U.S. cities such as San Francisco and Washington DC have already implemented a fee on plastic bags in retail or grocery shops, hence forcing customers to carry reusable bags.

Table 1. Recycling rate and GHGs Emissions by type of packaging waste (Recycling rate statistics come from the United States Environmental Protection Agency (US.EPA) and the UK Department of environment, food and rural affairs (DEFRA). GHG Emission coefficients are from Exiobase.)

Recycling rate for packaging waste	GHGs Emissions（tons）in per ton

US.EPA		UK.DEFRA		manufacture (worldwide average)	
Material	%	Material	%	Direct	Total
paper	78.16	paper	79.05	0.38	3.61
steel	72.97	steel	77.10	1.49	2.9
aluminum	36.41	aluminum	53.11	3.04	16.99
glass	33.22	glass	67.65	0.37	0.88
wood	27.09	wood	31.37	0.1	0.77
plastics	14.65	plastics	46.19	1.93	3.45

As shown in Fig. S1, the largest supplier of plastic packaging waste is Canada at 48.7 billion tons a year, i.e. 77.8% of the world total. Large endowments in oil and natural gas as well as close geographical proximity to the world's largest consumer of plastic, the United States, have contributed to this outcome. The next largest suppliers are two Asian economies, China and India, which have a population 35 times larger than Canada. They are followed by the USA and Brazil. Europe uses much less plastics in its packaging waste because it recognized and started tackling the problem relatively early on *(6)*. For instance, a directive adopted in 1994 set high standards of waste packaging recovery and recycling from all EU member countries. Ireland was also the first country to implement a significant tax on plastic bags –now raised to 22 euro cents- in 2002 while Germany has been requiring producers and distributors of packaging to pay for the collection of its waste since 1991. This extended producer responsibility approach has enlarged to other countries since then.

As shown in Fig. S2 and S3, the top 10 commodities and service sectors that induce the most plastic packaging waste are very similar to those that induce the most packaging waste in all materials (shown in Fig. 2 and 3). The most significant difference is that, at the world level, the "retail trade services" sector generates more plastics waste because of the shopping bags it offers than the "hotels and restaurants" sector.

Packaging used locally but wasted abroad

The internationalization of supply chain linkages and of final demand are responsible for 20.3% of the global packaging waste. 64.5% of that figure corresponds to packaging used in the good to be exported, in the transportation process, and is ultimately wasted in the destination country. As shown in Fig. 4 and Fig. S4-9, Canada, China, the USA and Greece are the top four economies in terms of exporting packaging waste. However, as indicated earlier, Canada stands out for its exports in plastic waste. The USA do too and that is for importing such a large amount of plastic that 76.6% of the world's plastic waste ends up in that country. Canada exports the rest of its plastics waste primarily to China and the rest of the Americas.

China is the largest exporter of paper waste (33.0% of the world's total) and glass waste (41.7% of the world's total). Its main destination markets are located in the rest of Asia and the Pacific region. Greece and the USA follow China for exporting glass waste at 13.9% and 10.9%, respectively. As

shown in Fig. S4-9, exports of packaging waste based on steel (mostly from Europe), wood (mostly from South Africa) and aluminum (almost entirely from the USA) are very minimal in comparison to the other materials.

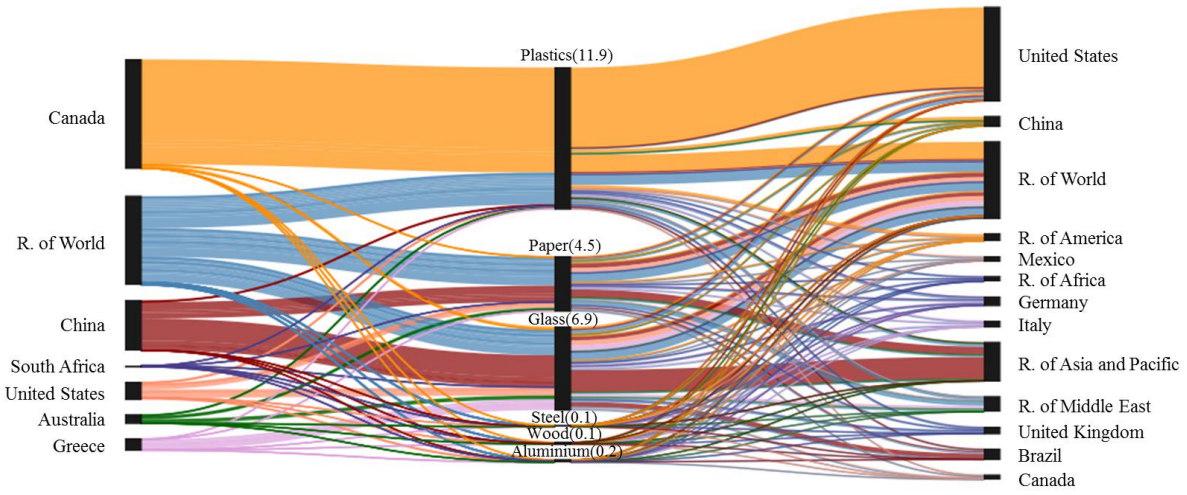

Fig. 4. Packaging by material used in the country of origin and wasted in the destination country. (This figure indicates the million tons of packaging waste that comes from the countries on the left and is exported to the countries on the right by material type. Each color represents a specific country of origin. The width of the flow represents the weight. The bars in the middle denote the corresponding packaging materials and the size of these bars is proportional to the weight of the packaging waste. ROW denotes the Rest of the World, i.e. the countries not included in the exports (left) or in the imports (right)).

Packaging wasted locally but induced by external demand

The remaining 35.5% of the total packaging waste embedded in international trade is the waste generated in the country of origin during the production process of a good that will be exported later on. Therefore, that waste remains in the country of origin. As shown in Fig. 5 and Fig. S10-15, Canada, China, Germany and Greece are the four countries with the most indirect packaging waste. The USA is the destination country that, by far, induces the largest amount of this type of waste. It is mostly composed of plastics and, again, it comes almost exclusively from its neighbor Canada. The top three materials are the same as above but the role of glass is now greater than the one of plastic and paper. One likely explanation is that this type of waste comes primarily from intermediate goods manufactured and transported within a single country. The fragility of this material and its high cost per unit of weight makes it a less desirable packaging choice than paper or plastic when cross-border hauling has to take place. The large majority of this type of glass waste (56.7%) comes from China.

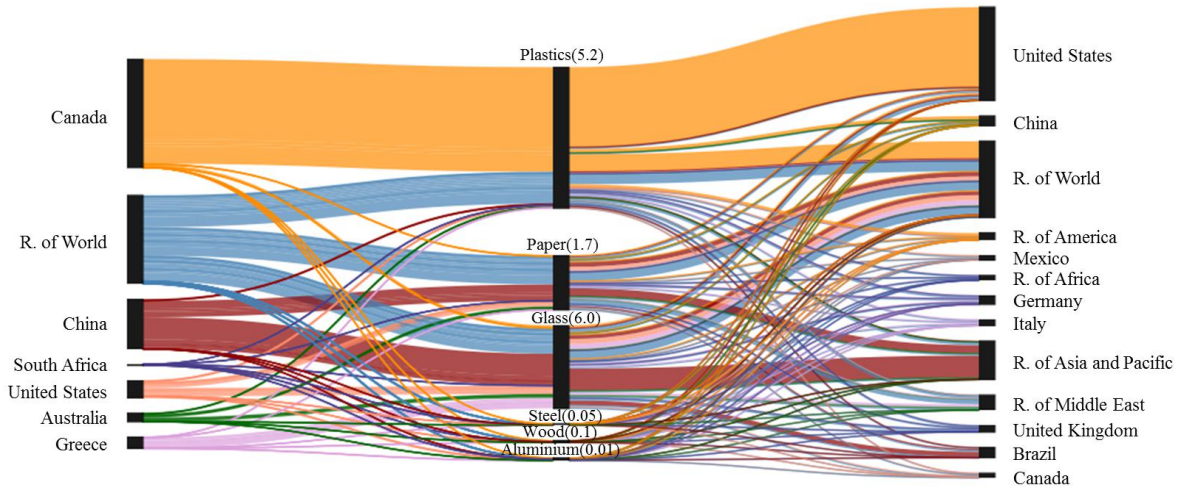

Fig. 5. Packaging by material induced by the destination country but used and wasted in the country of origin (This figure indicates the million tons of packaging waste indirectly induced by the production and export of commodities that leave the country of origin (left) to reach the country of destination (right). Each color represents a specific country of origin. The width of the flow represents the weight. The bars in the middle denote the corresponding packaging materials and the size of these bars is proportional to the weight of the packaging waste. ROW denotes the Rest of the World, i.e. the countries not included in the exports (left) or in the imports (right)).

Increasing public concerns about the growing amount of packaging waste, mostly single-use plastic waste and microplastics, found in rivers and oceans in addition to the recent decision by China and other East-Asian countries to stop taking on the rubbish of developed countries require a paradigm shift in our waste management practices. Because the world population and the average per capita consumption keep increasing, a recent United Nations report *(38)* anticipates "12 billion tons of plastic litter in landfills and the environment" by 2050 if our current consumptions patterns and waste management strategies continue (9 billion tons of plastic have been produced since plastic was introduced in the 1950's *(39)*).

Based on a recent database of international supply-chain linkages, our results show that it is primarily the waste in packaging for food and beverages that urgently needs to be tackled as, for instance, every 1 kg of fish consumed necessitates 7 kg of plastic packaging to be wasted along the supply-chain. In addition, we find that two countries, China and Canada, clearly stand out for generating a staggering 64.7% of the world's packaging waste. Canada, with a population 35 times smaller than China's, is exploiting its endowment in oil and natural gas to cheaply produce the chemical raw materials necessary for the manufacturing of polyethylene, the most popular plastic in the world. Yet, it would be naïve to blame all that waste on the lifestyle of the inhabitants of China and Canada. Indeed, respectively 12.9% and 28% of the packaging waste they produce is due to consumption in other countries (the world average is at 20.3%). In the case of China, it is mostly other Asian and Pacific countries that buy from it. In the case of Canada, packaging waste is quasi exclusively due to a sole country: the nearby United States.

The well-established international supply-chain linkages that support current consumption and production patterns oblige us to pay close attention to the challenges met when trying to control the externalities produced by other polluting economic activities. For instance, the production-based accounting approach that is currently used by the United Nations Framework Convention on Climate Change and the Kyoto Protocol to manage greenhouse gas (GHG) emissions would assign all the responsibility for the packaging waste management to the producers. While it could encourage high waste supplier countries like China and Canada to improve the recyclability of their packaging material or support biodegradable plastics, it could also support the relocation of the packaging industry from developed to developing countries so the former can meet their target. At the world level, it would be a zero-sum game or, eventually, a loss since developing countries would produce with less advanced technologies. Unfortunately, evidence shows that this process and result have taken place in the case of GHG emission intensive industries *(40, 41)*.

The opposite alternative, the full consumer responsibility system as promoted in the life-cycle assessment framework, has attracted quite some attention too *(42, 43)*. Consumers could, for instance, get a refund when returning empty plastic or glass bottles. However, it would lead to another extreme whereby a country could export all of the packaging it produces, enjoy the economic and employment benefits that come with it, but not bear any of the waste management cost *(44)*. We believe that since both importing and exporting countries benefit from trading with each other, then both of them should share the responsibility of packaging waste management. However, it does not have to be necessarily split 50-50 between both parties. Recent advances aiming at quantifying how to share the responsibility of traded emissions between producers, consumers and any intermediate member of the supply chain *(45-48)* could be enlarged to the case of packaging waste management. Unlike the full producer or full consumer responsibility schemes, the shared responsibility approach guarantees that reducing packaging waste is to the best interest of all, not just some, actors.

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53. The information about global efforts made by governments all over the world for reducing single-use plastics comes from: https://www.earthday.org/plasticban/

54. Reported by BBC NEWS: https://www.bbc.com/news/science-environment-47592111

55. Available at www.exiobase.eu/index.php/data-download/exiobase3hyb.

56. The supplier of packaging wastes denotes the producers of the wrapped goods for which the packaging material used and will be discharged as wastes by the consumers.

57. Calculated based on information from the World Bank database, base year 2017.

58. A direct requirement means that packaging is needed in the last step of the production process (assembly of the final product for delivery to final consumers).

59. The greenhouse gas emission coefficients are calculated based on the hybrid multi-region input-output table available from Exiobase.

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