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1. Abstract

Circular economy (CE) strategies are central in solving the waste management challenges of today, yet the global nature of the waste trade results in emissions and the export of negative environmental externalities to low-income countries. Here, we target a systemic challenge in the current indicators developed to measure more sustainable consumption and production progress. We argue that sustainable, circular solutions to recycling need to account for the negative externalities caused by the physical distance of the waste trade. We define the new concept “Small Circles” (SC) and suggest a new circularity indicator that can better ensure sustainability in implementing closed-loop strategies and thereby provide critical criteria to consider in pursuing CE. The SC approach advocates the need to manage the waste within a smaller geographical area of its origin to reduce the environmental burdens originating from the transboundary export of waste. Further, it ensures that the waste-producing regions take responsibility for their waste generation and management. If implemented appropriately, we argue that the SC approach could improve the transparency of the fate of waste and boost local opportunities through job creation and allow for the development of symbiotic relations among regional industries. The SC concept demands commitment from all stakeholders across the product value chain to extract value from the waste without jeopardizing sustainability goals. The application of the SC concept is explained by describing the sustainability challenges and opportunities related to plastic waste management in Europe. To concretize the SC approach and the circularity indicator further, the management of the plastic waste sourcing from the Norwegian fishing sector and plastic waste management in the US are used as case examples.

Keywords: Circular Economy Indicator, Industrial Symbiosis, Transparency, Waste Management, Waste Trade, Recycling

2. Introduction and Background

Marine plastic pollution, one of our time's most significant environmental threats, is a symptom of a malfunctioning plastics economy where only 9% of all plastics ever produced have been recycled, while up to 79% have been landfilled or dumped into the environment (Forrest et al. 2019). In addition, this marginal plastics recycling relies heavily on global value chains that lack transparency and are poorly regulated. Approximately 25% of all marine plastic litter is estimated to leak from within waste management systems, and plastic sent for recycling can leak from the value chain at any point (Marrs et al. 2019). Over half of the plastic waste earmarked for recycling is exported overseas, often from high-income countries to lower-income countries (Brooks et al. 2018), where there are no guarantees that plastic waste is efficiently recycled without adverse environmental consequences (Barnes 2019). A study by Law et al. (2020) estimates that approximately 0.15-0.99 MMT of plastic exported from the US alone for recycling are mismanaged in the importing countries annually (Law et al. 2020). The informal waste sector in the importing countries is forced to dump or burn worthless plastic materials due to a lack of proper waste management facilities. This not only contributes to the marine litter problem globally, with adverse effects on ecosystems and human health, but also causes severe degradation of the land, air and water locally compromising human well-being as documented in numerous studies (e.g. da Costa et al. (2016) and Wang et al. (2021) on effects of nano-plastics, Guo et al. (2020) and Kumar et al. (2020) on microplastic and associated chemical's impacts on soils, Beaumont et al. (2019) on marine plastic impact on ecosystem services, Abate et al. (2020) on plastic litter impacts on wildlife and aesthetics affecting human wellbeing, Waring et al., 2018 and UNEP 2016 on the human health impact of plastics via the food chain).

In effect, the global waste trade contributes to increasing negative environmental externalities as high-income countries export plastic waste to countries with insufficient waste management infrastructure and less stringent environmental and health policies. These trade patterns cause environmental degradation in the importing countries and thus an uneven divide of the negative externalities related to plastic waste management (Mah 2021). This uneven divide has potential environmental justice consequences for vulnerable and marginalized populations in the global south (Mah 2021). The adverse health-related externalities caused by mismanaged waste in countries with insufficient waste management systems include, e.g., flooding leading to spreading of diseases and risk of drowning due to waste blocking waterways, diarrhea diseases, the release of lethal pollutants to water and soil, and landslides at large dumpsites. As a result, up to one million lives are lost in developing countries yearly (Marrs et al. 2019).

The dependence on plastic waste export by high-income countries became particularly visible when China, the world's largest plastic scrap importer for the last three decades, implemented the National Sword policy (NSP) in 2018, banning all imports of scrap plastics. The NSP was implemented due to a series of environmental problems caused by the fact that up to 70.6% of the annual plastic waste exports, reaching 8.88 mT, were buried or mismanaged in the country (Wen et al. 2021). In the wake of the NSP, the cost of plastic recycling increased globally, more plastics ended up in landfills, incineration of plastics increased, and recyclables were stockpiled in countries traditionally exporting plastic waste to China (Brooks et al., 2018). The export of waste fractions from high-income countries to middle or low-income regions with insufficient waste management capacity (Barnes 2019) resulted in a ripple effect of import bans and taxes in these plastic waste destinations (Indonesia, Thailand, Malaysia, Vietnam and Taiwan) (INTERPOL 2020). In addition to transferring negative externalities from high to lower-income countries, the policy of distancing plastic waste by exporting creates artificially cleaner environments in the exporting countries, encouraging high plastic consumption as the actual costs of plastic consumption is not visible in these countries (Barnes 2019). There is an urgency to improve the recycling capacity in the waste exporting countries to reduce the negative externalities caused by the leakage of waste along the value chain and the transfer of negative externalities to lower-income countries (Barnes 2019).

To guide and incentivize countries towards plastic recycling practices that are more sustainable both locally and globally, we argue that the role of physical distance needs acute attention. The authors conceptualize this argument under the title "Small Circles" (SC), i.e., to improve the net global sustainability of the plastics economy, plastics recycling should rely on local or regional solutions rather than contributing to the global waste trade. We define the SC concept as: "*Reshaping the circularity strategies through containment of the geographical boundaries of end-of-life products to avoid financial, material and energy losses, and to ensure transparency and resilience in implementing strategies for the circular economy*." Here, the SC approach is elaborated by addressing the need for high-income countries to take responsibility for their own plastic waste by improving plastic recycling systems within the region. The need for local improvements in waste management facilities is identified as the most efficient, long-term solution to mismanaged plastic waste in several previous studies (e.g., Brooks et al. 2018; Wen et al. 2021; Barnes 2019; Deshpande et al., 2020).

The SC approach is further explained by developing a new indicator on the recycling rate that accounts for the holistic aspects of sustainability in realizing the circular economy principles. We present the comparative analysis of the traditional CE indicator “Recycling rate” with the modified indicator on recycling that incorporates the environmental cost of waste transport and the risk of exporting negative externalities. We further point out how incentives introduced by the SC concept would improve the net global sustainability of plastic waste management.

While the SC approach is relevant for all types of waste and at many regional scales, we use plastic waste and the trade flow between Europe and lower-income countries in Asia to illustrate the barriers and opportunities related to the sustainable development of circular processes. In the following sections, descriptions of initiatives to move towards more sustainable plastics economies will be discussed, considering the SC approach, pointing to how physical distance challenges some of the solutions proposed by global institutions and frameworks.

3. Current frameworks for Circular Plastics Economy and plastic trade

Currently, the challenges related to mismanaged plastics are acknowledged in both global and European sustainability and circularity strategies and frameworks. Goals, targets, and indicators have been developed to monitor and measure the sustainability of waste management. The United Nations' Sustainable Development Goals (SDGs) provide the overarching guidelines for developing socially, ecologically, and economically sustainable societies in the 21st century at a global level. Within the SDGs, the need for more sustainable consumption and production is highlighted in Goal 12: Ensure sustainable consumption and production patterns. Target 12.4 aims to by 2030, *achieve the environmentally sound management of chemicals and all wastes throughout their life cycle (…), significantly reduce their release to air, water, and soil to minimize their adverse impacts on human health and the environment*. The indicator for this target is the percentage of countries that meet the goals set in international multilateral agreements on hazardous waste and other chemicals, including the Montreal Protocol, Basel Convention, Rotterdam Convention and Stockholm Convention[1]. These regulatory frameworks are examples of efforts to gain control over the recycling value chains.

Plastic waste was included in the *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal* (Basel Convention) in 2019 to stop the transport of non-recyclable plastic waste from OECD to non-OECD regions. However, controlling all plastic waste trade at the point of export is impossible due to the complexity of the global shipping infrastructure and high container traffic volume (Ahmad Khan 2020). According to the European Trade Data, after a slight reduction in plastic waste exports

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[1] https://sdg-tracker.org/sustainable-consumption-productionO

outside OECD countries in the first month of implementing the plastic scrap trade restrictions, the exports increased again in the months to follow[2]. In addition, there is no clear definition of hazardous plastic waste in the Basel Convention, providing room for interpretation of the rules (Wen et al. 2021). This illustrates the difficulty of gaining control over the global plastic waste trade through regulatory frameworks.

SDG 12 target 12.5 points to the importance of implementing measures throughout the waste pyramid and aims to by 2030 "*Substantially reduce waste generation through prevention, reduction, recycling, and reuse".* The indicators for these targets being the national recycling rate / t of material recycled (indicator 12.5.1) (UN Statistical Commission, 2016). However, the recycling rate can be interpreted differently based on who is the interpreter; a waste management company, a policymaker, or a recycling company (Horta Arduin et al., 2019). Such ambiguity may result in misinterpretation of recycling rates in countries where waste fractions are segregated, collected, and exported for recycling rather than recycled locally. The main reason for this is that the traceability of exported waste is often not reflected in the reported recycling rate (Lazarevic et al., 2010). Net exporting regions, such as Europe, are therefore likely to report artificially higher recycling rates, as several of the global top destination countries for the plastic waste report of high mismanagement rates, e.g., India (87%), Indonesia (83%), Vietnam (88%) and Malaysia (57%) (Jambeck et al. 2015). The lack of knowledge regarding the actual recycling rates arises due to the lack of transparency of the plastic waste trade and destiny (Bishop et al., 2020), again highlighting the urgency to improve the plastics recycling capacity in exporting countries.

The current goals, targets, and indicators are limited with respect to creating globally sustainable, circular solutions to plastic waste. We argue that a major failure is that they do not account for the negative environmental externalities caused by the physical distance of the waste trade. In the following sections, we argue how the inclusion of physical distance

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[2] https://www.ban.org/plastic-waste-project-hub/trade-data/eu-export-data

can improve the current circularity and sustainability indicators using the case examples from Norway and the USA. Finally, we discuss the limitations of the proposed indicator, possible barriers and opportunities in operationalizing SC.

4. Small Circles Approach

We argue that in developing a circular plastics economy that contributes to net global sustainability, the negative externalities caused by the export of plastic waste should be considered in circularity and sustainability targets. The current targets and indicators should include not only the destiny of the waste in the country it is generated but also the negative externalities caused by CO_2 emissions due to transport of the waste and the destiny of the plastic waste in the importing countries (**Figure 1, point 2 and point 3**).

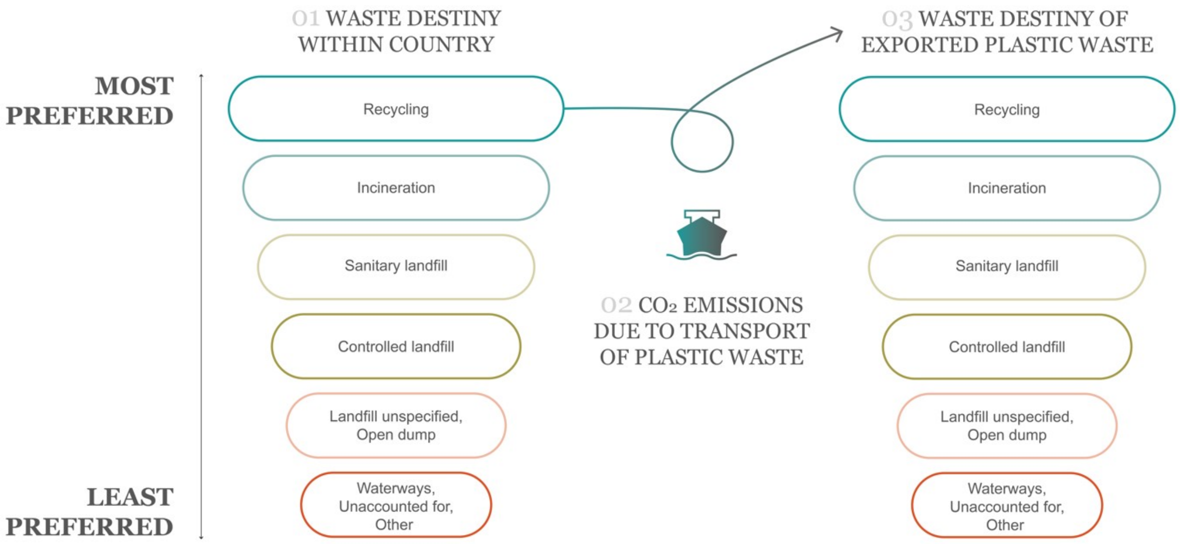

Figure 1: The Three stages of evaluation that the Small Circles indicator includes: 1 the End-of-Life (EoL)management of plastic waste inland, 2 emissions from waste transport, and 3 the EoL Management of plastic waste in the destination country.

As argued in section 2, the traditional indicator for circularity, the rate of recycling, inherits some shortcomings:

a) The environmental footprint of the transport of plastic waste is not included in the traditional recycling rate calculations.

b) The recycling rate indicator does not provide a clear picture of the total material recovered from the plastic waste generated.

Most of the transboundary export of plastic waste involves transport using trucks and sea freight, increasing the environmental footprint (e.g., through increased CO_2 emissions) of the plastic recycling systems. The export of waste between Europe and Asia generates additional environmental and economic burdens if the Global Warming Potential (GWP) is included due to additional CO_2 emissions and transport costs (Point 2, Figure 1). The following equations represent the burden of GWP impacts and cost implications from the traditional export (X_{TE}) and SC (X_{SC}) approach:

$$X_{TE} = X_{recycling} + X_{transboundary\ export} + X_{inland\ transport}$$

$$X_{SC} = X_{recycling} + X_{inland\ transport}$$

Here X in the environmental context represents CO_2 emissions and, in the economic context, represents transport costs for each scenario. The mathematical representation shows the additional effects of transboundary export arising in a traditional approach. These effects can only be minimized when exporting regions reduce, reuse, and recycle plastic waste within the region, making transboundary export distances to near zero (as seen from the X_{SC} equation).

Recycling rates vary according to which stakeholders in the plastics end-of-life (EoL) value chain calculate them. For example, for waste management companies, the recycling rate is understood as the ratio of waste segregated for recycling to the total waste generated. In contrast, a recycling company considers the recycling rate as a ratio of total material recycled to the total waste fed to the recycling plant (personal communication with recyclers within the study by Deshpande et al., 2020). SC is in line with the latter and argues that the actual recycling rate should be calculated as the overall ratio between all the waste generated and the total material recycled at the recycling point.

The inability of including these aspects in estimating the recycling rate provides an incomplete picture of the circularity of the plastics value chains. Therefore, to realize the CE and sustainability goals, the SC approach advocates a new adjustment to the indicator on recycling rate that encompasses the total distance covered for transporting the segregated waste for recycling and the actual recycling rate based on reported or estimated data on secondary plastic raw material production. The proposed adjustments in the indicator are elaborated mathematically through the following equation, whereas the application of the equation is illustrated using three different case studies ranging from Norway and the USA.

$$Circularity\ Indicator = \frac{\dfrac{Material\ recovered\ from\ Recycling\ (t)}{Total\ waste\ collected\ (t)}}{\dfrac{Transport\ inland\ distance\ (km) + Transport\ export\ distance\ (km)}{Per\ unit\ distance\ transported\ (km)}}$$

$$Circularity\ Indicator = \frac{{M_R}/{M_{TW}}}{T_{total}}$$

$$T_{total} = T_{inland} + T_{export}$$

Where, $T_{in} \geq 1$ km

Table 1: Calculating the circularity indicators for various waste management scenarios

When $M_R = M_{TW}$

The SC indicator rewards the reuse of waste material as per the waste hierarchy. Accordingly, M_R and M_{TW} are approximately equal when all the generated waste material is reused (original purpose or different from the initial use).

In equation 1, if we replace $M_R = M_{TW}$, the numerator equals 1, whereas the denominator remains the total distance transported for reusing, repurposing or recycling the waste. Therefore, the Circularity indicator can be calculated as:

$$Circularity\ indicator = \frac{1}{T_{total}}$$

When $T_T = 1$

This circularity indicator promotes finding localized solutions for closing the material loops and thereby reducing waste recycling and treatment distances. The total distance includes the distance transported inland, and the distance travelled in transboundary export of the waste. When waste is treated and recycled at the point of origin, the total transport distance is less than 1 km, thereby making the denominator 1. Therefore, the circularity indicator can be estimated as:

$$Circularity\ Indicator = \frac{M_R / M_{Tw}}{1}$$

When M_R=M_W and Tt=1

In the scenario where all the collected waste material is recycled, reused or repurposed at the point of collection without landfill and incineration worthy fractions, the circularity indicator shows unit values in both numerator and denominator. Such a case presents the complete circularity in the system with a maximum value of 1.

4.1 Application of the circularity indicator

This section presents the application of the circularity indicator on various regional case studies for managing plastic waste. The case examples are used to illustrate the concept presented in the SC approach.

Case-1: Plastic waste management from the fishing sector of Norway

The study by Deshpande (2020) presents the case of plastic waste management from the commercial fishing sector of Norway. The study found that the commercial fishing sector of Norway generates around 4200 t (M_{Tw}) of waste plastic (PP, PE and PA), which is collected at waste management companies (WMCs) in Norway. At the WMCs, the collected waste is segregated based on its quality. About 51% of the collected waste fishing gears have sufficient quality to be transported for further recycling. Interviews with waste managers and site visits were used to collect information on the transport inland and export distances, transportation mode, and the recycling efficiency of the recycling plant, including the typical fate of the waste generated through the recycling process. **Figure 2** represents the typical process flow diagram for end-of-life plastic, and associated values for internal and external transport distances (T_{in} and T_{ex}), and material recovered from recycling (M_R) (adapted from

Deshpande et al. (2020)). Accordingly, the circularity indicator for the fishing sector of Norway can be calculated using the equation defined above as:

$$Circularity\ indicator\ _{fishing\ sector\ of\ Norway} = \frac{1428/_{4200}}{(200 + 1200)} = 2.4e - 4$$

The indicator value of 2.4e-4 highlights the need for systemic improvement in the handling and management of EoL plastic waste to ensure circularity. The circularity (indicator value ~ 1) can be attained through improved waste collection and separation of reusable worthy fractions, increase the amount of fishing nets that are segregated out for recycling and the development of localized recycling infrastructure to avoid transporting waste fractions.

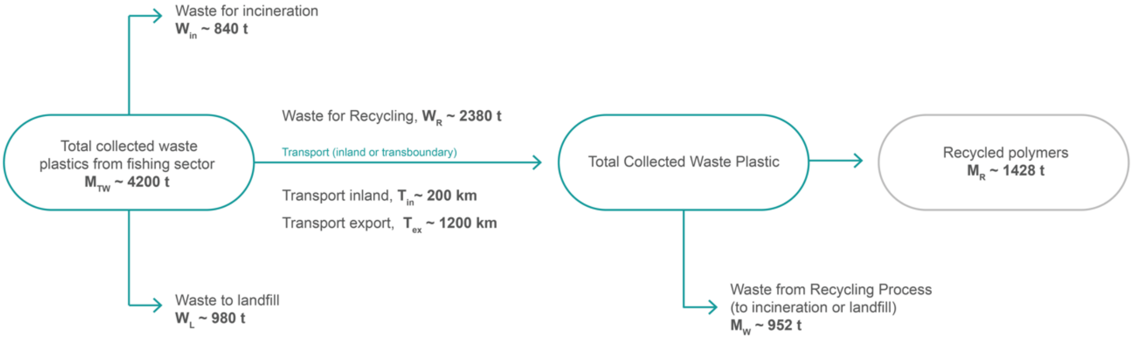

Figure 2: Case 1 illustrating the application of the SC indicator on recycling of fishing nets in Norway from collection, through transport, and recycling (modified from Deshpande, 2020).

Case-2: Circularity of the proposed eco-industrial cluster for plastic in Norway

Until 2017, industrial-scale recycling of plastic waste was unavailable in Norway. Consequently, the recyclable plastic material from fishing and aquaculture was sent out of Norway for mechanical recycling (Deshpande and Haskins, 2021). Industrial-scale recycling of plastic waste from the fishing and aquaculture sector began in Norway in the latter half of 2017. Although recycling of plastic fractions from these industries began in Norway, a significant fraction of plastic waste was still sent abroad for further processing and recycling.

A semi-structured interview of a regional recycler in Norway concluded that the recycling efficiency is 60% and the capacity of handling waste is around 35% of total waste generated from the fishing sector of Norway. Therefore, it is assumed that 65% of total plastic waste from the Norwegian fishing is shipped to the other eastern European countries for further processing (Deshpande et al. 2020).

In this case, where the fraction of waste from a similar sector is collected and treated on-site, whereas the other fraction is exported for recycling, the circularity indicator is calculated using the weighted aggregate method.

a) Collection and recycling of waste plastic in Norway

Recycling capacity ~ 35% and Recycling efficiency ~ 60%

Total Waste = 4200 t and treated in Norway ~ 1500 t

Recycled material =0.6*1500 = 900 t

T_T= T_{in}= 150 km (as export distance is 0)

$$Circularity\ indicator_1 = \frac{{}^{900}/_{1500}}{150} = 4e - 3$$

b) Fraction of waste sent for recycling

T_T= T_{in}+T_{ex}= 1400 km adapted from Deshpande et al. (2020)

Total material sent = 4200-1500 = 2700 t

Assuming the same recycling efficiency, recycled material = 0.6*2700 = 1620 t

$$Circularity\ indicator_2 = \frac{{}^{1620}/_{2700}}{1400} = 4.28e - 4$$

Therefore, the total circularity of the system can be estimated using a weighted average as

$$Circularity\ indicator_{total} = 0.35 * CI_1 + 0.65 * CI_2 = 1.66e - 3$$

Comparing the indicator value with Case-1 shows that improving local capacity to handle waste improves the circularity significantly. However, due to the relatively low capacity to manage waste inland, there is still room for improvement.

Case-3: Plastic waste management in the United States

After China banned all plastic scrap imports, other countries in South-East Asia experienced a massive spike in importing plastic waste. Malaysia alone experiences a tripling of imported waste PE from the US in 2017. According to the report presented by Greenpeace Malaysia (2018), Malaysia imported 195,445 mT of plastic waste from the US from January to July 2018 alone, compared to 97,544 mT for January to November 2017. Furthermore, the recent reports suggest that only 9% of the plastic segregated and sent from high-income countries was recycled, while the faith of most of the plastic waste is unknown. Therefore, to estimate the circularity indicator of plastic waste export from the US to Malaysia, the following values are obtained from Law et al. (2020) and Greenpeace Malaysia (2018).

$$M_{TW} = 195445 \text{ mT}$$

$$MR = 0.09 * 195445 = 17590 \text{ mT}$$

$$TT = Tin + Tex = 250 + 13{,}750 = 14000 \text{ km} \quad \text{(distances are assumed in km)}$$

$$Circularity\ indicator = \frac{17590/195445}{14000} = 6.42e-6$$

Therefore, the current circularity of the plastic waste management system between the US and Malaysia or any other South-Asian country is estimated to be far below the true circularity. Such low indicator values indicate of an urgent need for improved material recycling, preferably in the country of origin.

4.2 Realizing Circularity through SC approach

Apart from the circularity indicator, the SC approach highlights the need to estimate the GWP potential arising from the extensive transport of waste fractions. These transport-related CO_2 emissions can be estimated based on distance travelled using waste trade data (Kaza et al. 2018), type of transportation used, and the cargo's size, given assumptions regarding various factors such as fuel efficiency. The lack of transparency in waste trade makes it more challenging to calculate the actual recycling rate in importing countries. However, some simple assumptions can be made based on the existing data. Data on the destiny of waste for different countries are available through the World Bank's database (Kaza et al. 2018), where waste treatment data is reported according to 11 categories: open dump, landfill unspecified, controlled landfill, sanitary landfill, recycling, composting, anaerobic digestion, incineration, waterways, other and unaccounted for (Kaza et al. 2018). This data has been used to create global statistics on the destination of waste in terms of how much waste ends up in different quality landfills versus recycling, composting, and incineration (Kaza et al. 2018). Given a lack of transparency with respect to waste destiny in different countries, it can be assumed that the imported waste follows the same destiny as reported in the waste statistics of the World Bank. For example, if a large proportion of the plastic waste produced domestically ends up in landfills, the same destiny can be assumed for imported plastic waste. The waste treatment data can be organized according to the principles of the waste pyramid to rate the destiny of the plastic waste from *"most preferred"* to *"least preferred"* (Figure 1). If waste is exported for recycling to a country with a high proportion of its waste ending up in the “least preferred” categories, this will be considered when estimating the plastics recycling rate in the country of origin.

4.3 Limitations of the SC approach

We acknowledge the limitations caused by the lack of data on trade patterns and the final destinations of plastic waste[3], as many of the countries importing waste are also waste exporters. Germany, for example, imports waste for recycling but is also one of the leading waste exporters globally (Hsu et al., 2021). Furthermore, the calculations by Law et al (2020) illustrate the complexity of assumptions to be made. They make assumptions linking the level of income to the destiny of waste reported as "landfill unspecified" and the likely destiny of different plastic types. Further insight into how the SC indicator should be calculated will be gained by testing and challenging these assumptions.

The proposed SC indicator provides a new approach to calculate the circularity of a selected waste type. However, the indicator requires robust data that are currently not widely available due to lack of data collection in waste management. Additionally, the means of transport vary between waste exports (mainly sea freight) and inland transport (mainly transport by road and railroad). The heterogeneity in travel modes makes it challenging to estimate the actual value of transport distance. Another limitation of the indicator is that it only accounts for the physical distance waste is transported before its final treatment, failing to include the technical feasibility and sustainability of the waste treatment process. Although there are shortcomings in the proposed SC indicator, we believe that the approach can contribute to improving sustainability indicators and focus on the need for systems thinking when developing circular economy strategies and solutions. We hope the SC indicator will pave the way to coordinated science and technology efforts in achieving improved circularity and waste management.

5. Discussion

Regardless of the potential shortcomings in data availability and capturing the complexity of the waste trade, the adjusted indicator includes significant environmental burdens from the

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[3] https://comtrade.un.org/

transboundary export of waste plastic. However, there are potential challenges to SC implementation. At the same time, some significant opportunities may be lost if SC is not operationalized in the regions generating significant volumes of waste.

5.1 Challenges to realizing the Small Circles approach

The relatively high cost of domestic recycling has been a significant driver behind the export of plastic waste to lower-income countries (Xu et al. 2020). The global plastic waste trade has provided jobs in importing countries, but in some cases at high environmental costs, as reflected by import bans (Xu et al. 2020; Zhao et al. 2021). Most high-income countries have high recycling targets and high labour costs, resulting in economic incentives to send plastic to lower-income countries for recycling (INTERPOL 2020). Even the countries lacking ambitious recycling targets export a significant share of their plastic waste due to the market value of waste plastics as raw material (INTERPOL 2020). In addition, the high volume of traded goods between OECD countries and Asia incentivizes waste trade further. Keeping prices low for European companies to export to Asia is in the interest of shipping lines, as the alternative is to return containerships to Asia without cargo (INTERPOL 2020). Over the last decades, these dynamics have created robust trade patterns, including plastic waste trade between OECD countries and Asia. Currently, exporting waste plastics to Asia from Europe may be cheaper than recycling the materials within the region. Thus, there is no adequate financial or regulatory pressure forcing the niche of capacity building for localized handling and management of generated waste.

SC advocates the need for localized infrastructure to handle and manage generated waste volumes within the region. However, due to established supply chains exporting waste to low or middle-income countries, the recycling sector remains underdeveloped and immature in the EU and OECD regions (Xu et al., 2020). An analysis of plastic waste management from the Norwegian fishing sector illustrates some of the challenges of implementing more local recycling (Deshpande et al., 2020). The realization of SC needs good knowledge on material flows, amounts of waste types generated within the region, facilities dedicated to the collection, segregation, cleaning, and sorting of the waste types, supply chains transporting the waste from origin to the waste management companies, and finally dedicated facilities to recycle the waste fractions through best available technology. An analysis of these factors for the case of Norway concludes that currently, Norway cannot treat and manage the 4000 t of plastic waste generated from commercial fishing in the region annually (Deshpande et al., 2020). As seen with the implementation of China's NSP, policies hindering waste export risk diverting plastic waste from recycling to landfills and incineration, as there is a lack of facilities in Europe to treat this waste locally (Xu et al 2020). After the Chinese ban, however, some European countries started investing in new technologies to allow efficient sorting and washing of plastics (Barnes 2019). Thus, local recycling or other circular economy solutions must be developed to contribute to the SC philosophy after an initial time lag.

The current plastics recycling systems have developed over several decades. Challenging them requires detachment from path dependency and technological lock-ins (Korhonen et al. 2018). Although localized efforts to recycle and manage plastic waste seem the preferred alternative within a CE strategy, this shift demands creative decision making across the value chain actors. However, most businesses tend to be risk-averse and avoid venturing into unknown futures (Korhonen et al., 2018). A systems approach focusing on reducing the production of plastics, the increase of plastics recycling, and the demand for secondary plastics as the primary raw material for new products is needed to develop sustainable circular economies (Korhonen et al 2018). Wen et al. (2021) voiced the need for coherent policy incentives and monetary investments for managing waste locally. The barriers of initial higher investments for capacity building in realizing SC could be resolved through coherent partnerships with regulatory, societal, and industrial actors.

Although realizing SC may demand immediate pressure on the economy, we argue that in the long term, investing in SC approach may provide several benefits to the regions and operationalizing SC should be considered as a “Disruptive technology” (Bower and Christensen, 1995).

5.2 Opportunities of the Small Circles Concept

While data availability and the complexity of the waste trade is a limitation to correctly calculating an SC waste management indicator, implementation of such an indicator would make the actual cost of plastic waste export more apparent. Implementing the SC indicator could incentivize the industry and regulators to improve the transparency of plastic waste exports. Transparency of the fate of exported waste could be considered an essential responsibility of the exporting nation. Realizing the SC approach could also reduce the negative externalities of exported waste on importing countries.

SC is in line with the European Strategy for Plastics in a Circular Economy of increasing plastic recycling rates (European commission 2018b). Currently, less than 30% of plastic waste generated in the EU is collected for recycling, a significant share of which is exported to lower-income countries with varying environmental standards. The European Strategy signals high ambitions for recycling plastic waste within the EU boundaries, supported by the goal; “*the export of poorly sorted plastics waste has been phased out*”, in addition to “*By 2030, all plastics packaging placed on the European market is either reusable or can be recycled in a cost-effective manner*”, and “*By 2030, more than half of all plastics are to be recycled, and the recycling capacity is to be increased and modernized*”. Furthermore, in 2019, a single-use plastics (SUPs) and fishing gear directive was introduced to eliminate the 10 most found SUPs from the European market and extend the producer responsibility (EPR) for fishing gear to reduce the leakage of abandoned, lost, or otherwise discarded fishing gear into the environment.

The EU’s aim for more cost-efficient recycling and modernizing recycling facilities could make recycling more economically viable at a regional level. The benefits of increased recycling capacity are also underlined by the 200 000 new jobs that can be created in the recycling industry in Europe by 2030 (EC, 2018). More ambitious and coordinated EPR policies, including the whole lifecycle of plastic products, from cradle to cradle, could contribute to a more circular plastics economy in Europe (Leal Filho et al. 2019). An efficient EPR scheme that includes regulations regarding transboundary waste trade could assist in developing, promoting, and regulating coherent strategies that minimize waste generation and further ensure total disclosure of environmental burdens of exporting waste.

Local solutions may also include opportunities for eco-industrial networks, creating new industrial sectors to utilize recycled material through innovative circular business models. The transboundary export of waste, on the other hand, hinders local attempts to develop sophisticated EoL value chains for material recovery and recycling (Deshpande and Haskins, 2021). Eco-industrial networks, also known as industrial symbiosis, provide a systemic theoretical foundation, where waste from one sector could be processed and used as a raw material in other industrial sectors (Chertow, 2007). Realizing SC within the region provides several opportunities to establish new industrial symbiotic relations, improving the resource efficiency and self-reliance of the collaborating sectors. An example of such value capture is the mechanical recycling of plastic polymers PP, PE and PA generated from EoL fishing gears and ropes in Norway, which results in the production of HDPE and LDPE polymers upon recycling. These recycled polymers are then successfully used in injection moulding technologies by various plastic industries in the Nordic region (Deshpande and Haskins, 2021). Another example is the attempt to use EoL products from the Norwegian fishing sector as raw material in brackets and walkways used by the aquaculture sector in the region. The interviews with the plastic industry managers conducted by Vildåsen (2018) revealed that cost-cutting and reduced environmental impacts, together with localized value creation, are motivating the Norwegian plastic industries to aim for localized strategies for CE that are in line with the SC approach.

Realizing such symbiotic relationships within a region needs systemic transformation of ‘doing business’ and building partnerships among the various stakeholders within the region. The opportunities of capturing value from waste through local circular solutions are not new. Lowe and Evans (1995) illustrate how industrial parks or regions can benefit from each other through a web of interaction among companies, where energy and materials flow between different industries. The concept is defined explicitly for cities by Van Berkel et al. (2009) and elaborated by several authors (Prendeville et al., 2018, Williams, 2019, Zeller et al., 2019) by exemplifying localized solutions to metabolize waste generated in the cities. If waste plastic is exported out of the region, the region misses the opportunity to earn and retain economic benefits from material and energy recovery (Deshpande et al., 2020). Currently, only 11% of the recycled plastic materials return to the European market as secondary materials (Hsu et al. 2021). SC may promote localized closed-loop systems, thereby increasing the retainment and reuse of the recycled material. The current export of waste diminishes the need and incentive to capture the value of waste through recycling technologies.

The availability and improvement in local recycling capacity in high-income countries could also reduce the region's dependency on the global waste trade. This self-reliance on waste management would detach the region from complex socio-political changes driving the waste trade. The Chinese NSP proved how dependency on a single importer makes the exporters vulnerable to market changes in the importing country (Brooks et al. 2018). The importance of the flexibility of value chains and self-reliance was also highlighted during the Covid-19 pandemic when the accessibility of plastic raw materials was weakened between Asian and Norwegian actors (Deshpande and Haskins 2021).

The export of plastic waste from the significant plastic waste-producing regions motivates the increase in plastic consumption by creating artificially cleaner environments (Barnes 2019). The call for greater control over plastics’ EoL solutions in the SC approach places the responsibility of the plastic waste on those creating it (e.g. polluter pays principle), potentially affecting the way plastics are consumed in these regions. Simon et al. (2021) highlight the need to shift the focus from downstream solutions for plastics to upstream solutions, to reduce the negative impacts caused by mismanaged plastics. However, recycling methods need to be assessed for their sustainability to create sustainable, circular plastic economies where recycled materials replace virgin plastic materials. Therefore, the SC approach complements the much-needed efforts higher up in the waste pyramid, which is where we need to move to secure a more sustainable plastics consumption (Barnes 2019).

6. Conclusions and future prospects

To incentivize long-term, sustainable solutions to mismanaged plastic waste, we argue that physical distance should be included as an indicator in plastics recycling targets. Implementation of a Small Circle (SC) indicator accounting for physical distance transported by waste material before being recycled or recovered provides the holistic coverage of the circular economy and sustainability targets, which again secures more sustainable management of waste, both environmentally, socially, and economically. We argue that the SC approach has the potential to improve the net global sustainability of waste management through a reduction of negative externalities, such as emission from transports, leakage of waste into the environment, and adverse health and environmental consequences of waste trade in the importing regions. The implementation of the SC approach may demand high initial investment costs due to the restructuring of value chains and establishment of improved coordination of stakeholder actions throughout the product life cycle.

To prove the principles and conceptual setting of the SC approach, case studies of plastic waste management was presented. As for all case study research, some of the findings are general and applicable elsewhere, whereas others are more specific and need contextual interventions before adopting them. Still, we believe that the indicator can be widely applied to account for the environmental costs of the current waste trade, incentivise local CE solutions and improved transparency of the recycling value chain. However, to develop strategies for circularity within the limits of sustainability, sector-specific research is needed to generate evidence on mass flows of wastes from the specific regions. The feasibility of recycling and recovery strategies should be studied to ensure agreement with the laws of thermodynamics. The strategies for handling and managing waste must then be designed in collaboration with local stakeholders to ensure optimal implementation of the SC concept. Finally, we argue that the SC approach must be treated as a destructive technology to approach the circular economy. When implemented appropriately, the SC concept can bring several societal benefits, sourcing from e.g., eco-industrial partnerships, job creation, resource conservation and waste minimization, reduced dependence on imported and virgin raw materials, as well as increased innovation in design within smaller geographical areas.

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7. References

ABATE, T. G., BÖRGER, T., AANESEN, M., FALK-ANDERSSON, J., WYLES, K. J. & BEAUMONT, N. 2020. Valuation of marine plastic pollution in the European Arctic: Applying an integrated choice and latent variable model to contingent valuation. Ecological Economics, 169, 106521.

AHMAD KHAN, SABAA. 2020. “Clearly Hazardous, Obscurely Regulated: Lessons from the Basel Convention on Waste Trade.” AJIL Unbound 114: 200–205. https://doi.org/10.1017/aju.2020.38.

BARNES, STUART J. 2019. “Out of Sight, out of Mind: Plastic Waste Exports, Psychological Distance and Consumer Plastic Purchasing.” Global Environmental Change 58 (September): 101943. https://doi.org/10.1016/j.gloenvcha.2019.101943.

BEAUMONT, N. J., AANESEN, M., AUSTEN, M. C., BÖRGER, T., CLARK, J. R., COLE, M., HOOPER, T., LINDEQUE, P. K., PASCOE, C. & WYLES, K. J. 2019. Global ecological, social and economic impacts of marine plastic. Marine Pollution Bulletin, 142, 189-195.

BISHOP, G., STYLES, D. & LENS, P. N. L. 2020. Recycling of European plastic is a pathway for plastic debris in the ocean. Environment International, 142, 105893.

BOWER, J. L. & CHRISTENSEN, C. M. 1995. Disruptive technologies: catching the wave.

BROOKS, A. L., WANG, S. & JAMBECK, J. R. 2018. The Chinese import ban and its impact on global plastic waste trade. Science Advances, 4, eaat0131. https://doi.org/10.1126/sciadv.aat0131.

CHERTOW, M. R. 2007. “Uncovering” Industrial Symbiosis. Journal of Industrial Ecology, 11, 11-30.

DA COSTA, J. P., SANTOS, P. S. M., DUARTE, A. C. & ROCHA-SANTOS, T. 2016. (Nano)plastics in the environment – Sources, fates and effects. Science of The Total Environment, 566-567, 15-26.

DESHPANDE, P. C. & HASKINS, C. 2021. Application of Systems Engineering and Sustainable Development Goals towards Sustainable Management of Fishing Gear Resources in Norway. Sustainability, 13, 4914.

DESHPANDE, P. C. P., GASPARD; BRATTEBØ, HELGE; FET, ANNIK M. 2020. Using Material Flow Analysis (MFA) to generate the evidence on plastic waste management from commercial fishing gears in Norway. Resources, Conservation & Recycling: X, 5, 100024.

DESHPANDE, P. C., SKAAR, C., BRATTEBØ, H. & FET, A. M. 2020. Multi-criteria decision analysis (MCDA) method for assessing the sustainability of end-of-life alternatives for waste plastics: A case study of Norway. Science of The Total Environment, 719, 137353.

EUROPEAN COMMISSION. 2018B. “A European Strategy for Plastics in a Circular Economy.” European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A28%3AFIN.

FORREST, ANDREW, LUCA GIACOVAZZI, SARAH DUNLOP, JULIA REISSER, DAVID TICKLER, ALAN JAMIESON, AND JESSICA J. MEEUWIG. 2019. “Eliminating Plastic Pollution: How a Voluntary Contribution From Industry Will Drive the Circular Plastics Economy.” Frontiers in Marine Science 6 (September): 627. https://doi.org/10.3389/fmars.2019.00627.

FREE, C. M., JENSEN, O. P., MASON, S. A., ERIKSEN, M., WILLIAMSON, N. J. & BOLDGIV, B. 2014. High-levels of microplastic pollution in a large, remote, mountain lake. Marine pollution bulletin, 85, 156-163.

GUO, J.-J., HUANG, X.-P., XIANG, L., WANG, Y.-Z., LI, Y.-W., LI, H., CAI, Q.-Y., MO, C.-H. & WONG, M.-H. 2020. Source, migration and toxicology of microplastics in soil. Environment International, 137, 105263.

HORTA ARDUIN, R., GRIMAUD, G., MARTÍNEZ LEAL, J., POMPIDOU, S., CHARBUILLET, C., LARATTE, B., ALIX, T. & PERRY, N. 2019. Influence of scope definition in recycling rate calculation for European e-waste extended producer responsibility. Waste Management, 84, 256-268.

HSU, W.-T., DOMENECH, T. & MCDOWALL, W. 2021. How circular are plastics in the EU?: MFA of plastics in the EU and pathways to circularity. Cleaner Environmental Systems, 2, 100004.

INTERPOL. 2020. “Emerging Criminal Trendsin the Global Plastic Waste Market since January 2018.” INTERPOL General Secretariat. https://www.wwf.no/assets/attachments/INTERPOL-Report_Criminal-Trends-Plastic-Waste.pdf.

JAMBECK, JENNA R., ROLAND GEYER, CHRIS WILCOX, THEODORE R. SIEGLER, MIRIAM PERRYMAN, ANTHONY ANDRADY, RAMANI NARAYAN, AND KARA LAVENDER LAW. 2015. “Plastic Waste Inputs from Land into the Ocean.” Science 347 (6223): 768. https://doi.org/10.1126/science.1260352.

KAZA, SILPA, LISA C. YAO, BHADA-TATA PERINAZ, AND FRANK VAN WOERDEN. 2018. What a Waste 2.0 : A Global Snapshot of Solid Waste Management to 2050. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/30317.

KORHONEN, JOUNI, ANTERO HONKASALO, AND JYRI SEPPÄLÄ. 2018. “Circular Economy: The Concept and Its Limitations.” Ecological Economics 143 (January): 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041.

KUMAR, M., XIONG, X., HE, M., TSANG, D. C. W., GUPTA, J., KHAN, E., HARRAD, S., HOU, D., OK, Y. S. & BOLAN, N. S. 2020. Microplastics as pollutants in agricultural soils. Environmental Pollution, 265, 114980.

LAW, KARA LAVENDER, NATALIE STARR, THEODORE R. SIEGLER, JENNA R. JAMBECK, NICHOLAS J. MALLOS, AND GEORGE H. LEONARD. 2020. “The United States’ Contribution of Plastic Waste to Land and Ocean.” Science Advances 6 (44): eabd0288. https://doi.org/10.1126/sciadv.abd0288.

LAZAREVIC, D., AOUSTIN, E., BUCLET, N. & BRANDT, N. 2010. Plastic waste management in the context of a European recycling society: Comparing results and uncertainties in a life cycle perspective. Resources, Conservation and Recycling, 55, 246-259.

LEAL FILHO, WALTER, ULLA SAARI, MARIIA FEDORUK, ARVO IITAL, HARRI MOORA, MARIJA KLÖGA, AND VIKTORIA VORONOVA. 2019. “An Overview of the Problems Posed by Plastic Products and the Role of Extended Producer Responsibility in Europe.” Journal of Cleaner Production 214 (March): 550–58. https://doi.org/10.1016/j.jclepro.2018.12.256.

LUSHER, A. 2015. Microplastics in the marine environment: distribution, interactions and effects. Marine anthropogenic litter. Springer, Cham.

MAH, ALICE. 2021. “Future-Proofing Capitalism: The Paradox of the Circular Economy for Plastics.” Global Environmental Politics 21 (2): 121–42. https://doi.org/10.1162/glep_a_00594.

MALAYSIA, G. 2018. The recycling myth: Malaysia and the broken global recycling system. Kuala Lumpur: Greenpeace Malaysia. Retrieved November, 5, 2019.

MARRS, DYLAN GEORGE, IEVA RUČEVSKA, AND PATRICIA VILLABURRIA-GÓMEZ. 2019. “Controlling Transboundary Trade in Plastic Waste (GRID-Arendal Policy Brief).” http://www. grida.no/activities/311.

PICÓ, Y. & BARCELÓ, D. 2019. Analysis and Prevention of Microplastics Pollution in Water: Current Perspectives and Future Directions. ACS Omega, 4, 6709-6719.

PRENDEVILLE, S., CHERIM, E. & BOCKEN, N. 2018. Circular cities: Mapping six cities in transition. Environmental innovation and societal transitions, 26, 171-194.

SIMON, NILS, KAREN RAUBENHEIMER, NIKO URHO, SEBASTIAN UNGER, DAVID AZOULAY, TRISIA FARRELLY, JOAO SOUSA, ET AL. 2021. “A Binding Global Agreement to Address the Life Cycle of Plastics.” Science 373 (6550): 43–47. https://doi.org/10.1126/science.abi9010.

UN STATISTICAL COMMISSION, U. 2016. Inter-agency and Expert Group on Sustainable Development Goals indicators (IAEG-SDG). E/CN.3/2016/2/Rev.1, United Nations, 2016 UN-Economic and Social Council.

UNEP, U. 2016. Frontiers 2016 Report: Emerging Issues of Environmental Concern. United Nations Environment Programme Report, Nairobi.

VAN BERKEL, R., FUJITA, T., HASHIMOTO, S. & GENG, Y. 2009. Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997–2006. Journal of Environmental Management, 90, 1544-1556.

WANG, L., WU, W.-M., BOLAN, N. S., TSANG, D. C. W., LI, Y., QIN, M. & HOU, D. 2021. Environmental fate, toxicity and risk management strategies of nanoplastics in the environment: Current status and future perspectives. Journal of Hazardous Materials, 401, 123415.

WARING, R. H., HARRIS, R. & MITCHELL, S. 2018. Plastic contamination of the food chain: A threat to human health? Maturitas, 115, 64-68.

WEN, ZONGGUO, YILING XIE, MUHAN CHEN, AND CHRISTIAN DOH DINGA. 2021. “China’s Plastic Import Ban Increases Prospects of Environmental Impact Mitigation of Plastic Waste Trade Flow Worldwide.” Nature Communications 12 (1): 425. https://doi.org/10.1038/s41467-020-20741-9.

WILLIAMS, J. 2019. Circular cities. Urban Studies, 56, 2746-2762.

WWF, ELLEN MACARTHUR FOUNDATION, AND BCG. 2020. “The Business Case for a UN Treaty on Plastic Pollution.” WWF.

XU, WEN, WEI-QIANG CHEN, DAQIAN JIANG, CHAO ZHANG, ZIJIE MA, YAN REN, AND LEI SHI. 2020. “Evolution of the Global Polyethylene Waste Trade System.” Ecosystem Health and Sustainability 6 (1): 1756925. https://doi.org/10.1080/20964129.2020.1756925.

ZELLER, V., TOWA, E., DEGREZ, M. & ACHTEN, W. M. J. 2019. Urban waste flows and their potential for a circular economy model at city-region level. Waste Management, 83, 83-94.

ZHAO, CHANGPING, MENGRU LIU, HUANZHENG DU, AND YU GONG. 2021. “The Evolutionary Trend and Impact of Global Plastic Waste Trade Network.” Sustainability 13 (7): 3662. https://doi.org/10.3390/su13073662.