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Perspective

Reshaping global policies for circular economy

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ABSTRACT

Circular economy is recognized as a powerful integrative framework envisioned to solve societal problems linked to environmental pollution and resource depletion. Its adoption is rapidly reforming manufacturing, production, consumption, and recycling across various segments of the economy. However, circular economy may not always be effective or even desirable owing to the spatiotemporal dimensions of environmental risk of materials, and variability of global policies. Circular flows involving toxic materials may impose a high risk on the environment and public health such that overemphasis on anthropogenic circularity is not desirable. Moreover, waste flows at a global scale might result in an uneven distribution of risks and costs associated with a circular economy. Among other benefits, circular economy needs to generate environmental advantages, energy savings, and reductions of greenhouse gas emissions. Recent attempts to implement the carbon neutrality strategy globally will likely push the circular economy further into more economic sectors, but challenges remain in implementing and enforcing international policies across national boundaries. The United Nations Basel Convention on the Transboundary Movement of Hazardous Waste and their disposal is used here as an example to illustrate the challenges and to propose a way forward for anthropogenic circularity.

1. Introduction

A linear model of resource consumption with a take-make-dispose pattern has caused severe environmental disasters, adverse human health impacts, and rapid depletion of non-renewable energy and material resources (Didenko et al., 2018; Feng & Yan, 2007; Johansson, 2021). Concerns about the limit to the linear economy-driven growth are intensifying in many countries, and the collective responsibility to emergency situations such as global climate change has contributed to the urgency to find and implement alternative models (IRP, 2017). Meanwhile, the sustainable development goals set by the United Nations (UN) are calling for improvements to human well-being, refocusing economic prosperity, and protection of healthy environments.

The circular economy framework is regarded as a potentially powerful strategy for solving the problems created by the linear economy model of industrial activities and gross economic growth. Circular economy describes an industrial system focused on closing the loop for material and energy flows and contributing to long-term environmental sustainability and resource conservation (Geng et al., 2013). However, operating the circular economy is also generating some concern among scholars and practitioners, and has inspired research questions along the lifecycle of materials and energy resources (Clark et al., 2016).

Circular economy is charged not only with improving the efficiency of resource conservation, but also with reducing waste through anthropogenic circularity, charactering reuse, remanufacturing, recycling, and recovery (Pauliuk et al., 2021; Zeng & Li, 2021). It is enabled by two approaches, namely a closed loop for material circularity in the same function or an open loop for material used for other functions. With the challenge of resource availability of e.g. rare earth minerals, implementation of circular

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economy is increasingly deployed to meet demands of an increasingly digital configuration of social interactions and commerce (Sovacool et al., 2020). Additional benefits of circular economy are energy savings and reductions in greenhouse gas emissions (Mayer et al., 2019), while urban mining decreases demand for virgin mining (Olivetti & Cullen, 2018; Wang et al., 2021).

The progressive industrial revolution of the past two centuries relied on the extraction of natural resources from the lithosphere, and then they are processed and transformed into desired products, which at the end of their useful life (EoL) became wastes of uncertain environmental fate. In this one-directional logistics, most materials flow to sinks, at which the notorious substances contaminate the environment. It has been recognized that some materials in EoL products may be transformed into useful products again, in a process known as reverse logistics (waste reclamation), through the collection, component harvesting, refurbishment, reuse, remanufacturing, recycling, and material extraction process, all positioned within the circular economy framework to decrease externalized waste (Fig. 1) (The Ellen MacArthur Foundation, 2012; Zeng & Li, 2018, 2021).

Nations vary according to policies and practices to adopt the circular economy framework. For example, Germany and Japan have comprehensive plans for recycling (through Germany's Closed Substance Cycle and Waste Management Act of 1996 and Japan's 2000 Fundamental Law for Establishing a Sound Material-cycle Society). The European Commission announced a Circular Economy Package in December 2015, and launched the latest Circular Economy Action Plan in measures in 2020 (European Economic and Social Committe, 2020). In the United States, the Comprehensive Environmental Response, Compensation and Liability Act has stimulated numerous corporate recycling and resource recovery initiatives, although challenges remain in the adverse impacts of inefficient recycling processes, such as recent problems in lead-acid battery recycling (Ogunseitan, 2016). The United States also has a notable regional program such as the Zero Waste scheme in San Francisco, California. In China, rapid consumption of the world's resources has incentivized regulatory policies to promote the recirculation of waste materials (Mathews & Tan, 2016).

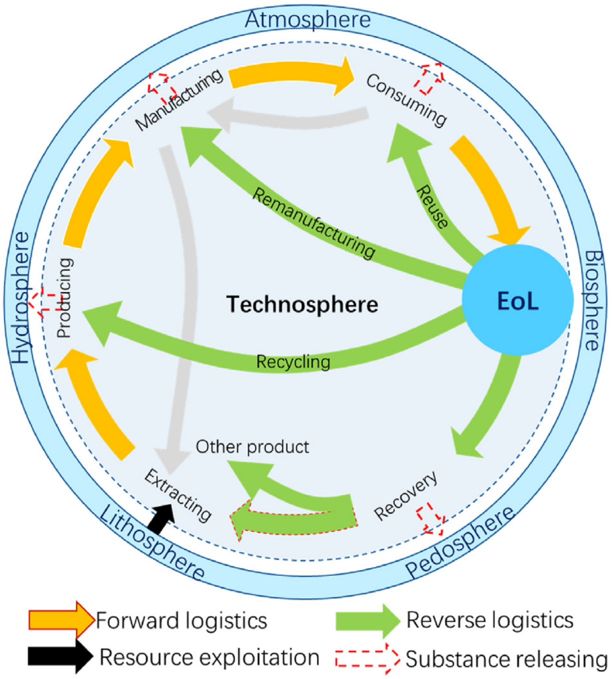

Fig. 1. Circular economy linking forward and reverse logistics towards circularity (Zeng & Li, 2021, reprinted with permission © The Author(s)).

2. Circular economy progress: international challenges and opportunities

2.1. Controlling toxic releases across material lifecycles

Despite inherent toxicity to most living organisms, some elements such as lead and mercury are still allowed to be used with exceptions by RoHS Directive due to their irreplaceable functions. Despite attempts to use policies and economic incentives to avoid toxic releases and exposures during the lifecycle of such products, fugitive emissions occur and vulnerable populations and environmental are impacted adversely. Therefore promoting recycling of such materials is incompatible with long-term ecological sustainability (Ayres, 1992). For example, tin-lead solder even in low concentration was used extensively in electronic packaging. The typical EoL disposal of products made with such solders have contaminated the environment in the absence of adequate recycling policies (Ogunseitan et al., 2009). Without a strategy to embed informal recycling into the circular economy of such products, it will be impossible to avoid the release of toxic materials into the environment with impacts on ecosystems and human health (Heacock et al., 2016; Li et al., 2015b). Insufficient investments in environmental protection in low- and middle-income countries have resulted in a high burden of toxic pollution-related mortality rates. Therefore, it may be more desirable to eliminate some toxic materials from the circular economy of products to avoid the disincentive of diminishing returns on investments in collection and recycling.

On the other hand, another vital aspect of circular economy is the issue of mixing materials in recycling that can compromise the quality of the products. During the reuse and remanufacturing, the quality of material and function can commonly go down (Ohno et al., 2014; Winterstetter et al., 2021). Regarding the recycling and recovery, for instance, metal in product can be high quality as pure metal for high recyclability, or low quality as alloy for low recyclability, difficult to recover as pure metal (Fang et al., 2018; Kanwal et al., 2021; Zeng & Li, 2016). The same plastic resins, which are non-toxic for specific electronic applications, can become hazardous for other applications, such as toys and food containers (Leslie et al., 2016; van Eygen et al., 2018). Old iron scrap often downgrades via oxidation, weathering, or process. Mixing iron scrap with copper and tin reduces the quality of recycled steel (Daehn et al., 2017; Dworak & Fellner, 2021; Ohno et al., 2015). Therefore, some additional process like smelting could be needed to raise the material quality.

2.2. International flows of materials and products

International flow of materials and wastes is essential for closing gaps in the circular economy. However, the international flow challenges the protection of health and the environment. For example, lead-acid batteries and electronic waste (e-waste) are used here to illustrate the weaknesses at the start and end of transnational flows. In the US, a major producer of spent LABs (formally recognized as hazardous waste) have been exported to relatively poor countries for the end material recovery (Ogunseitan, 2016). Illegal transboundary flow of e-waste occurred frequently in the 2000s from affluent industrialized nations to poorer countries (Lee et al., 2018; Lepawsky, 2015; Li et al., 2015a). The improper recycling in poverty regions resulted in disastrous consequences for environmental quality and public health. The sustainability of long-distance transportation of materials and waste are depending on fluctuations of transportation cost, potential for leakage, energy expenditure, carbon footprint, and supply chain logistics (Dietzenbacher et al., 2020; Xu et al., 2020). Thus, lifecycle thinking includes acknowledgment of trade-off subject to subjective values of stakeholders within the circular economy.

2.3. *Harmonization of international policies and regulation*

The international regulatory framework for materials, manufactured products, and wastes has been reinforced since the 1990s from regional to global jurisdictions. Globally, the Basel Convention on the Transboundary Movement of Hazardous Waste and their disposal focus on protecting human health and the environment against the adverse effect of hazardous wastes, which were notoriously and unfairly traded across national boundaries due to imbalance and diversity of policies, regulation, and value systems in various countries and regions. The EU, Japan, and China are leading in e-waste regulation and policy, but most countries with economies in transition are still at the early stages (Fig. 2). Such loopholes of policies and regulations keep the international flow of toxic products unencumbered. Locally, for instance, in China, some provinces and cities established special regulations to prohibit the hazardous waste flow stemmed from other regions, considering carrying capacity of the local ecosystems.

Within individual countries such as China, regulation and policy have stipulated the rigorous governance for products and components. Two major gaps exist in the existing regulation: lack of adequate attention to the recovered materials and substances and no control of substances to avoid toxic metals which are manufactured in new products (Zeng et al., 2017), thus amplifying potential risks on the environment and human health beyond secure disposal practices.

2.4. *Classification of anthropogenic resources*

Raw material supply is of key relevance for nations, industries, and modern lifestyles. Today, primary raw materials dominate raw material supply, but secondary raw materials are getting more attention in the context of climate protection and circular economy. In circular economy, material recovery from residues is of crucial concern. In recent years, several case studies estimated the availability of secondary raw material from anthropogenic resources in analogy to primary raw materials from geogenic sources. For instance, JORC (2012) and National Instrument 43–101 (OSC, 2016) were used to classify downstream projects (Blasenbauer et al., 2020) and the McKelvey box (McKelvey & Kleepe, 1976) and the United Nations Framework Classification for Resources (UNFC) (Heiberg et al., 2018; UNECE, 2020) were used to classify national material stocks and flows, post-consumer residues and landfills (Winterstetter et al., 2021). The initiatives for classifying anthropogenic resources facilitate the development of recovery projects, but are challenged by essential differences between natural and anthropogenic resources. Anthropogenic resources are, for instance, ferrous and non-ferrous metals, precious metals, plastics, or rubber in residues such as e-waste, automobiles, wires, cables, and packages.

In contrast to natural resources, anthropogenic resources are influenced by anthropogenic activities. Thus, the most salient feature of an anthropogenic resource is that its constituents are all manufactured and refined. Therefore, de-manufacturing processes are needed to deal with residues. This implies that urban mining differs from virgin mining. The known natural mineral stocks decrease with exploitation and increase with newly discovered mineral sources. In contrast, anthropogenic stocks are converted, at one point or another, into residues, which then can be recovered during recycling (Fig. 2). The classification of anthropogenic resources, in analogy to geogenic resources, enables comparable estimates of anthropogenic and geogenic resource availabilities. It facilitates sustainable recovery project development and national resource management if environmental, social, and governance criteria are considered. These factors can be integrated into the UNFC in order to communicate the viability of recovery projects to governments, investors, industry, and the public.

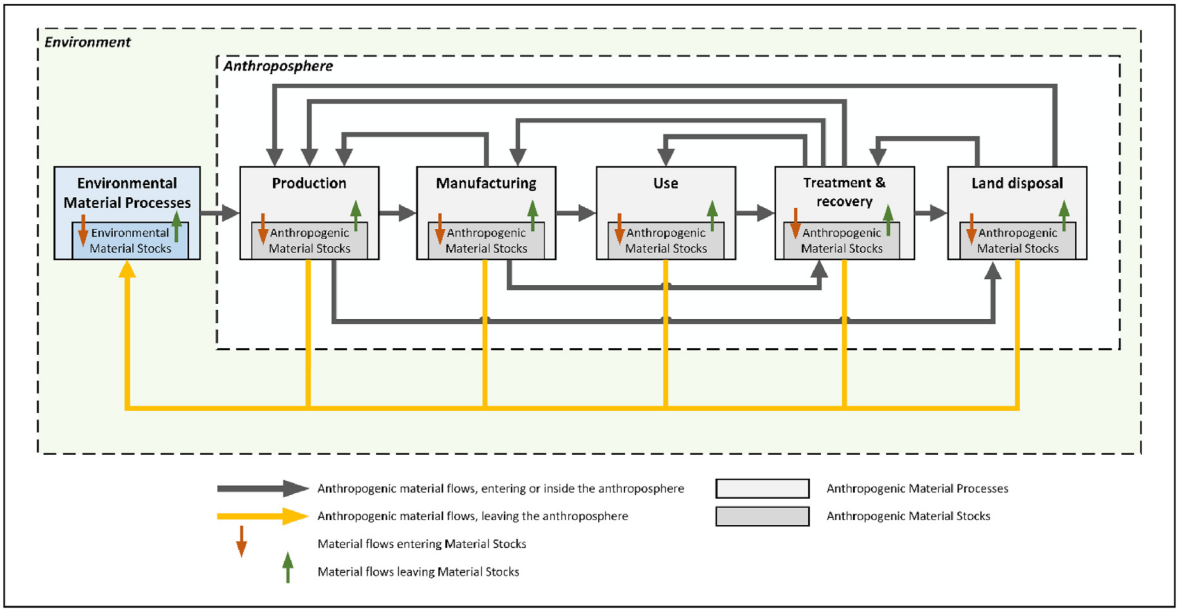

Fig. 2. Material flow of resources in the environment and anthroposphere (UNECE, 2018, reprinted with permission © The Author(s)).

3. The way forward

At the global scale, restrictions on the treatment and recycling of toxic materials, and restricted circulation can be considered urgent for efficient circular economy in the near future. This approach needs to be translated and integrated into the UN's Basel Convention. At the countries or regional scale, more regulatory policies related to waste management should be implemented for toxic materials and substances, and even prohibition of their recycling in backward technological circumstances. Among other instruments, the UNFC can be a potential enabler to develop sustainable recycling projects in alignment with the UN sustainable development goals.

Although spatiotemporal, geographic, and international dimensions pose major challenges for the effectiveness of circular economy, there are opportunities to transition from a linear model of material and energy flows, including innovations in technical and policy capacities. Despite many economic, environmental, and social challenges, the harmonization and compatibility of regulations and policies among the countries, regions, and even provinces are needed in the circular economy policy support framework so that the updating and revising of circular economy implementation in the US, the EU, Japan, and China can be achieved without delay.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Ayres, R. U. (1992). Toxic heavy metals: Materials cycle optimization. *Proceedings of the National Academy of Sciences of the United States of America, 89*, 815–820.

Blasenbauer, D., Bogush, A., Carvalho, T., Cleall, P., Cormio, C., Guglietta, D., Fellner, J., Fernández-Alonso, M., Heuss-Aßbichler, S., Huber, F., et al. (2020). *Knowledge base to facilitate anthropogenic resource assessment. Deliverable of COST Action Mining the European Anthroposphere*. https://doi.org/10.5281/zenodo.3739164

Clark, J. H., Farmer, T. J., Herrero-Davila, L., & Sherwood, J. (2016). Circular economy design considerations for research and process development in the chemical sciences. *Green Chemistry, 18*, 3914–3934.

Daehn, K. E., Cabrera Serrenho, A., & Allwood, J. M. (2017). How will copper contamination constrain future global steel recycling? *Environmental Science & Technology, 51*, 6599–6606.

Didenko, N., Klochkov, Y., & Skripnuk, D. (2018). Ecological criteria for comparing linear and circular economies. *Resources, 7*, 48.

Dietzenbacher, E., Cazcarro, I., & Arto, I. (2020). Towards a more effective climate policy on international trade. *Nature Communications, 11*, 1130.

Dworak, S., & Fellner, J. (2021). Steel scrap generation in the EU-28 since 1946—sources and composition. *Resources, Conservation and Recycling, 173*, 105692.

European Economic and Social Committe. (2020). *Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions: A new circular economy action plan for a cleaner and more competitive europe*. https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF.

Fang, S., Yan, W., Cao, H., Song, Q., Zhang, Y., & Sun, Z. (2018). Evaluation on end-of-life LEDs by understanding the criticality and recyclability for metals recycling. *Journal of Cleaner Production, 182*, 624–633.

Feng, Z. J., & Yan, N. L. (2007). Putting a circular economy into practice in China. *Sustainability Science, 2*, 95–101.

Geng, Y., Sarkis, J., Ulgiati, S., & Zhang, P. (2013). Measuring China's circular economy. *Science, 339*, 1526–1527.

Heacock, M., Kelly, C. B., Asante, K. A., Birnbaum, L. S., Bergman, A. L., Brune, M. N., Buka, I., Carpenter, D. O., Chen, A., Huo, X., et al. (2016). E-Waste and harm to vulnerable populations: A growing global problem. *Environmental Health Perspectives, 124*, 550–555.

IRP. (2017). *Assessing global resource use: A systems approach to resource efficiency and pollution reduction. A report of the international resource Panel (IRP)*. Nairobi, Keny: United Nations Environment Programme.

Johansson, N. (2021). Does the EU's action plan for a circular economy challenge the linear economy? *Environmental Science & Technology, 55*, 15001–15003.

JORC. (2012). *Australasian code for reporting of exploration results, mineral resources and ore reserves. Joint Ore Reserves Committee (JORC)*. The Australasian Institute of Mining and Metallurgy, Australian Institute of Geoscientists and Minerals Council of Australia.

Kanwal, Q., Li, J., & Zeng, X. (2021). Mapping recyclability of industrial waste for anthropogenic circularity: A circular economy approach. *ACS Sustainable Chemistry & Engineering, 9*, 11927–11936.

Lee, D., Offenhuber, D., Duarte, F., Biderman, A., & Ratti, C. (2018). Monitour: Tracking global routes of electronic waste. *Waste Management, 72*, 362–370.

Lepawsky, J. (2015). Are we living in a post-Basel world? *Area, 47*, 7–15.

Leslie, H. A., Leonards, P. E. G., Brandsma, S. H., de Boer, J., & Jonkers, N. (2016). Propelling plastics into the circular economy—weeding out the toxics first. *Environment International, 94*, 230–234.

Li, J., Zeng, X., Chen, M., Ogunseitan, O. A., & Stevels, A. (2015a). Control-alt-delete": Rebooting solutions for the E-waste problem. *Environmental Science & Technology, 49*, 7095–7108.

Li, J., Zeng, X., & Stevels, A. (2015b). Ecodesign in consumer electronics: Past, present, and future. *Critical Reviews in Environmental Science and Technology, 45*, 840–860.

Mathews, J. A., & Tan, H. (2016). Circular economy: Lessons from China. *Nature, 531*, 440–442.

Mayer, A., Haas, W., Wiedenhofer, D., Krausmann, F., Nuss, P., & Blengini, G. A. (2019). Measuring progress towards a circular economy: A monitoring framework for economy-wide material loop closing in the EU28. *Journal of Industrial Ecology, 23*, 62–76.

McKelvey, V., & Kleepe, T. (1976). *Principles of the mineral resource classification system of the US Bureau of Mines and US geological survey*. Washington: USBM and USGS.

Ogunseitan, O. A. (2016). Power failure: The battered legacy of leaded batteries. *Environmental Science & Technology, 50*, 8401–8402.

Ogunseitan, O. A., Schoenung, J. M., Saphores, J. D., & Shapiro, A. A. (2009). The electronics revolution: From E-wonderland to E-wasteland. *Science, 326*, 670–671.

Ohno, H., Matsubae, K., Nakajima, K., Kondo, Y., Nakamura, S., & Nagasaka, T. (2015). Toward the efficient recycling of alloying elements from end of life vehicle steel scrap. *Resources, Conservation and Recycling, 100*, 11–20.

Ohno, H., Matsubae, K., Nakajima, K., Nakamura, S., & Nagasaka, T. (2014). Unintentional flow of alloying elements in steel during recycling of end-of-life vehicles. *Journal of Industrial Ecology, 18*, 242–253.

Olivetti, E. A., & Cullen, J. M. (2018). Toward a sustainable materials system. *Science, 360*, 1396–1398.

OSC. (2016). *National instrument 43-101: Standards of disclosure for mineral projects*. Ontario Securities Commission. https://www.osc.ca/sites/default/files/pdfs/irps/ni_20160509_43-101_mineral-projects.pdf.

Pauliuk, S., Heeren, N., Berrill, P., Fishman, T., Nistad, A., Tu, Q., Wolfram, P., & Hertwich, E. G. (2021). Global scenarios of resource and emission savings from material efficiency in residential buildings and cars. *Nature Communications, 12*, 5097.

Sovacool, B. K., Ali, S. H., Bazilian, M., Radley, B., Nemery, B., Okatz, J., & Mulvaney, D. (2020). Sustainable minerals and metals for a low-carbon future. *Science, 367*, 30–33.

The Ellen MacArthur Foundation. (2012). *Towards the circular economy Vol. 1: An economic and business rationale for an accelerated transition*.

UNECE. (2018). *Specifications for the application of the united nations framework classification for resources to anthropogenic resources*. United Nations Economic Commission for Europe (UNECE). https://doi.org/10.5281/zenodo.3759026

UNECE. (2020). *United nations framework classification for resources*. United Nations Economic Commission for Europe (UNECE).

Van Eygen, E., Laner, D., & Fellner, J. (2018). Integrating high-resolution material flow data into the environmental assessment of waste management system scenarios: The case of plastic packaging in Austria. *Environmental Science & Technology, 52*, 10934–10945.

Wang, T., Berrill, P., Zimmerman, J. B., & Hertwich, E. G. (2021). Copper recycling flow model for the United States economy: Impact of scrap quality on potential energy benefit. *Environmental Science & Technology, 55*, 5485–5495.

Winterstetter, A., Heuss-Assbichler, S., Stegemann, J., Kral, U., Wäger, P., Osmani, M., & Rechberger, H. (2021). The role of anthropogenic resource classification in supporting the transition to a circular economy. *Journal of Cleaner Production, 297*, 126753.

Xu, Z., Li, Y., Chau, S. N., Dietz, T., Li, C., Wan, L., Zhang, J., Zhang, L., Li, Y., Chung, M. G., et al. (2020). Impacts of international trade on global sustainable development. *Nature Sustainability, 3*, 964–971.

Zeng, X., & Li, J. (2016). Measuring the recyclability of e-waste: An innovative method and its implications. *Journal of Cleaner Production, 131*, 156–162.

Zeng, X., & Li, J. (2018). Urban mining and its resources adjustment: Characteristics, sustainability, and extraction. *Scientia Sinica Terrae, 48*, 288–298 (in Chinese).

Zeng, X., & Li, J. (2021). Emerging anthropogenic circularity science: Principles, practices, and challenges. *iScience, 24*, 102237.

Zeng, X., Yang, C., Chiang, J., & Li, J. (2017). Innovating e-waste management: From macroscopic to microscopic scales. *Science of the Total Environment, 575*, 1–5.

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