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# Incorporating Health Impacts into the Circular Economy: A Comprehensive Assessment of Worker and Consumer Safety in the Plastic Production and Recycling Industries†

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**Abstract:** The world's plastic production is expected to double in the next 20 years, causing significant environmental and sustainability challenges. That's where the necessity to shift to a circular economy (CE) from a linear economy becomes evident. CE aims to solve the huge plastic waste challenges by introducing newer strategies of repairing, recycling, reusing, and designing products with a longer life cycle and lesser environmental impacts. While most of the existing approaches to quantifying circularity consider different economic and environmental factors, they often neglect the health aspects. This article emphasizes the need to incorporate health impacts into the concept of the circular economy, focusing on the plastic industry. It highlights the health effects on the workers during production and on consumers throughout the product's life span, including recycling and reuse. The health risks associated with the occupational safety hazards, chemicals utilized in plastic production and recycling, and chemicals released from plastic containers (such as carcinogens, bisphenol A, and phthalates) during prolonged use were analyzed. It also examines the challenges of connecting health impacts to circularity and proposes methods to address worker and consumer health aspects in assessing circularity. Three case studies of plastic production and recycling industries are presented to recommend that despite significant recycling efforts, circularity scores of their products need to be lower due to the substantial health impacts experienced by the workers.

**Keywords:** Circular economy; Plastic pollution; Health impacts; Sustainability

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## 1. Introduction

A circular economy is centered on the concept of converting products that have reached the end of their useful life into valuable resources for others. This strategy is geared towards establishing closed loops within industrial systems, with the goal of minimizing waste [1].

Social acceptance is a pivotal factor in the successful implementation of Circular Economy (CE) initiatives within urban settings, as it involves transformative changes in consumption, production, and waste management practices that necessitate active participation and endorsement from society [2]. A prime example of this is the essential role of citizens' acceptance in ensuring the efficacy of waste separation at the source programs, a cornerstone of sustainable municipal solid waste management [3]. In addition to social acceptance, the transition to a circular economy can yield significant energy savings. This transition is reinforced by strategies like increased recycling, the utilization of recycled materials, and the development of products designed for a second life and ease of disassembly, all of which are instrumental in driving the energy transition [4]. Notably, recycling processes within the circular economy framework can contribute to the conservation of critical materials vital for renewable power technologies [4], [5]. Moreover, technological innovations have been instrumental in enhancing recycling processes within the polymers industry. Innovations such as solvent extraction, plastic-to-fuel conversion, and depolymerization have emerged as key advancements [6]. Additionally, the adoption of biodegradable or compostable polymers, bio-based polymers, waste separation technologies, and advanced methods for characterizing waste plastics collectively contribute to the circular economy [7]. The collection of Municipal Solid Waste (MSW) at the source is a fundamental component of urban waste management. Effective waste collection systems play a pivotal role in reducing the volume of waste destined for landfills and increasing recycling rates [8], [9]. Furthermore, citizen participation in waste separation at the source significantly enhances the efficiency of waste collection. Local governmental policies and regulations occupy a central role in promoting and facilitating the transition to a circular economy. These policies encompass a wide spectrum of actions, including strategy development, capacity building, economic incentives, and regulatory measures [10]. Cities and regions, for instance, can actively foster the circular economy by envisioning a strategic roadmap, implementing multi-level governance effectively, ensuring policy coherence, engaging stakeholders, and adopting a suitable scale [10]. The healthcare sector has exhibited a growing interest in embracing the tenets of a circular economy. Circular design principles offer healthcare organizations opportunities to embrace sustainable business models that enhance resilience and improve health outcomes [11]. Moreover, transitioning to a circular economy allows healthcare institutions to diminish their environmental footprint and contribute to sustainable development [12].

A review of the literature reveals that the existing methods of calculating circularity primarily focus on environmental and economic factors, often neglecting health considerations. Though some authors emphasized the importance of addressing health impacts, nobody suggested to incorporate it into the calculation of circularity. To bridge this gap, this article emphasizes the need to account for health impacts on workers and consumers throughout a product's lifecycle, including recycling. In a comprehensive study conducted by Han Wei in 2018, the health implications of circularity were examined through an in-depth analysis at Ziya Circular Economy Park, one of North China’s largest e-waste recycling facilities. Despite the ecological risk assessment revealing considerable concentrations of Cu, Sb, Cd, Zn, and Co in the soil of the investigated area, the health risk assessment methodology proposed by the USEPA found no significant health risks to the local population [13]. In 2019, Wright C.Y. highlighted in their study that the shift towards a circular economy in low- and middle-income countries involves initiatives to derive value from waste. However, these endeavors are associated with environmental health hazards, including exposure to dangerous and toxic work conditions, emissions, materials, and infectious diseases [14]. In a 2020 study, P.J.M. Van Boerdonk underscored the necessity of integrating customer value creation and activities within a circular business model. The empirical research, which was centered on the customer’s viewpoint, revealed that customer values in a Circular Economy are paradoxical and warrant thorough investigation. [15]. Subsequently in 2021, Aublet-Cuvelier proposed that while the circular economy presents an opportunity for improved integration of prevention and necessitates significant organizational and production changes, it could also inadvertently impact workers’ safety and health negatively. Consequently, issues related to occupational safety and health (OSH) might need to be incorporated into new processes and organizations, contingent on the pace of the circular economy’s development over the next two decades. [16]. In a 2022 study, Ed Cook posited that as initiatives to mitigate plastic pollution and promote a circular economy intensify, there will be a need for the development of new infrastructure. However, the selected processes and systems should not have detrimental impacts on human health or the environment. He further noted that most countries in the Global South are yet to establish comprehensive waste management systems for non-hazardous waste, let alone specialized facilities for handling hazardous by-products [17]. In their 2022 study, Rada, E.C. and Tubino M. took a unique approach to addressing health concerns associated with circularity. They emphasized the critical role of thermochemical valorisation of municipal solid waste (MSW) in achieving the ultimate Circular Economy (CE) goals, and stressed the need for comprehensive and accurate health risk assessment procedures that are specifically designed for populations residing within the influence area of a waste-to-energy (WtE) plant [18]. In 2023, Cook, Derks, and Velis highlighted the public health challenges associated with the global growth of the plastics reprocessing sector in a circular economy. They found that despite strict regulations and industrial practices, small amounts of harmful substances in discarded plastics can bypass safety measures and re-enter the product cycle post-recycling, posing significant health and safety risks [19]. Kirchherr et al. (2017) conducted a comprehensive literature study, which revealed the existence of 114 distinct definitions of the circular economy concept. This finding shows that most of the definitions prioritize the concepts of reduce, reuse, and recycle (3R), but no exploration regarding quantifying the health aspects [20]. Later on De Pascale (2021) reviewed 61 circular economy indicators and identified three key factors: reduction, reuse, and recycling within social, economic, and environmental dimensions. This review also showed limited focus on health conditions [21]. The Organization for Economic Co-operation and Development (OECD) has published an inventory of circularity indicators that illustrates the distribution of indicators among different sectors from 2018 to 2020. Table 1 shows that the inventory has five category of indicators, none specifically focused on human health [22].

**Table 1.** Distribution of circularity indicators.

| Sector | Percent Indicators | Function |
|---|---|---|
| Environment | 39% | Measures the direct impact on the ecosystem |
| Governance | 34% | Focuses on indicators related to the education, capacity building, and regulation |
| Economic and Business | 14% | Measures the monetary value added by the circular economy |
| Infrastructure and Technology | 8% | Analyzes the tools, technologies, and spaces that boost the circular economy |
| Jobs | 5% | Discusses employment and human resources related to the circular economy |

## 2. Material and Methods

It is evident from the literature that recycling contributes to a greater circularity rating according to most of the studies. For this reason, some prominent plastic recycling facilities of Bangladesh were studied to assess the respective health conditions of the workers who remain behind the screen for such greater circularity achievement. The results of those studies are summarized below:

### *2.1. Study of RFL Plastic Recycling Industry*

The RFL Plastic Recycling Factory in Bangladesh, one of the largest in the country, has a daily production capacity of 20 metric tons for polypropylene products and employs 78 workers in two shifts. Safety measures, such as gloves, masks, helmets, and fire safety equipment, have been implemented to protect the workers, but they are insufficient given the number of workers and the inherent risks. Burning a portion of the factory's waste exposes workers to harmful smoke, increasing the risk of respiratory diseases. Additionally, the crushing process generates microplastic particles and dust, posing a health hazard. The factory also suffers from significant noise pollution, with sound levels ranging from 80 to 100 decibels.

### *2.2. Study of Showari Ghat Plastic Recycling Industries*

The recycling industries of Showari Ghat, Old Dhaka, Bangladesh lack proper infrastructure and have no safety system at all. The workers are not skilled. These industries produce plastic from virgin resins as well as recycled plastic. They provide little protection for workers, and its structure is extremely vulnerable. They don't have a dust concentrator, thus small plastic particles in the air aren't reduced. They wash their broken plastic in the river (Buriganga) water that is extremely polluted already. This water has many heavy particles that are hazardous to human health.

### *2.3. Study of Nimtoli Plastic Recycling Facilities*

In Nimtoli, Old Dhaka, Bangladesh, around 28-30 local plastic recycling facilities handle used plastics. On average, each factory transports 7-8 vans of polyethylene and 5-7 vans of bottles daily, with each van carrying approximately 200 kg of bottles and 400 kg of polyethylene. PET bottles and HDPE containers are cleaned and sold, mainly to the cattle feed industry. These collected plastic items are also distributed to local businesses in Showari Ghat and nearby areas of Old Dhaka. During the cleaning process within the factory, fine plastic particles and dust saturate the environment to the extent that visibility is severely reduced within a ten-foot radius. Unfortunately, the workers engaged in these cleaning activities lack proper protective gear, with some resorting to using towels to cover their noses for minimal protection. Notably, these workers belong to the lower socioeconomic class and face challenges in meeting their family responsibilities, often prioritizing them over health concerns.

## **3. Results and Discussion**

In the plastic manufacturing and recycling sectors, a wide range of chemicals are used, leading to various health hazards. From the studies on plastic production and recycling industries mentioned earlier, we have identified the presence of Polyvinyl Chloride (PVC), dioxins, Phthalates, styrene, toluene, xylene, Hydrochloric acid (HCl), Sodium Hydroxide (NaOH), volatile organic compounds (VOCs), antioxidants, heavy metals such as As, Pb etc. in the industries as well as recycled goods.

### *3.1. Chemicals in Plastic Production:*

The plastic production process involves the use of several chemicals, including Polyvinyl Chloride (PVC), dioxins, Phthalates, and styrene. The production of PVC can lead to the release of hazardous substances such as dioxins and phthalates. Dioxins are recognized carcinogens that can potentially harm the immune and reproductive systems [23]. Phthalates, on the other hand, can have lasting effects when there is prolonged exposure during manufacturing, packaging, or transportation processes of plastic-based goods. These effects can be detrimental to the endocrine system, pregnancy outcomes, and the growth and development of children. They can also affect the reproductive systems of both young children and adolescents [24]. Styrene is another chemical used in the plastic production process. It is classified as a potential carcinogen, and exposure to high concentrations over a prolonged period can harm the central nervous system [25] (pp. 4-6). Polyethylene terephthalate (PET) is generally considered safe for use in food containers. However, there are concerns about the potential leaching of antimony, a heavy metal used in PET manufacturing. This could pose health risks if present at elevated levels [26].

### *3.2. Chemicals in Plastic Recycling:*

In the recycling industry, a variety of chemicals are commonly used, each with its own potential health impacts. Solvents such as toluene and xylene, for instance, are frequently used in plastic recycling. These solvents can cause irritation to the eyes, nose, and throat, and prolonged exposure can even damage the central nervous system and various organs [27]. Hydrochloric acid (HCl), another prevalent chemical, is used in the recycling of PVC plastics. Contact with HCl can result in skin, eye, and respiratory irritation. In severe cases, inhalation can lead to significant respiratory distress [28]. Sodium Hydroxide (NaOH), also known as caustic soda, is utilized in certain recycling processes. It can cause burns to the skin and eyes, as well as the respiratory tract. If ingested or inhaled, it may harm internal organs [29]. Adhesive removers are used to remove labels and adhesives from plastic containers. These removers may contain volatile organic compounds (VOCs) that have been linked to health issues such as decreased lung function and respiratory problems, especially in children [30]. Lastly, the health effects of antioxidants and stabilizers used in the industry can vary greatly depending on their composition. For example, some primary aromatic and heterocyclic amines used in commercial stabilizers have been shown to possess carcinogenic or mutagenic properties [31].

Plastic recycling industries transform various plastic items into uniform pellets, which are easy to store and process, and are used to create a variety of plastic products. However, these pellets can contain heavy metals like arsenic, cadmium, and chromium, which are known carcinogens and pose a significant risk to workers. Table 2 details the levels of heavy metal exposure and associated risks [32].

**Table 2.** Exposures and risk levels of heavy metals from pellets.

| Metal | Risk Type | Daily possible exposure (mg·(kg·day)$^{-1}$) | Risk level | Acceptable risk level (US EPA*) |
| --- | --- | --- | --- | --- |
| Arsenic | Carcinogenic | $1.514\times10^{-5} - 7.303\times10^{-4}$ | $2.271\times10^{-5} - 1.095\times10^{-3}$ | $10^{-6}$ to $10^{-4}$ |
| Cadmium | Carcinogenic | $4.799\times10^{-8} - 2.611\times10^{-5}$ | $2.928\times10^{-7} - 1.593\times10^{-4}$ | |
| Chromium | Carcinogenic | $2.824\times10^{-4} - 7.827\times10^{-3}$ | $1.412\times10^{-4} - 3.906\times10^{-3}$ | |
| Lead | Noncarcinogenic | $1.344\times10^{-7} - 1.187\times10^{-5}$ | $9.601\times10^{-11} - 8.480\times10^{-9}$ | |

*US EPA - U.S. Environmental Protection Agency

In addition to chemical exposure, noise pollution is an important concern within plastic production and recycling sectors. The presence of excessive noise in the workplace has been associated with adverse health effects such as hearing impairment, elevated blood pressure, and the development of various cardiovascular conditions. Recent research has shown a significant correlation between occupational noise exposure (beyond 80 dB) and development of hypertension. A dose-response connection has been observed, wherein the likelihood of hypertension increases as noise levels escalate. Moreover, substantial data exists indicating that noise exposure might contribute to the occurrence of work-related injuries, diabetes, auditory neuroma, and difficulties during pregnancy [33].

### *3.3. Consumer Health Risks*

The use of plastics has been linked to a variety of health issues due to the presence of certain chemicals. These chemicals can disrupt hormonal balance, leading to reproductive issues such as infertility, early puberty, and birth defects. A study published in the journal Environmental Health Perspectives revealed that exposure to Bisphenol A (BPA), a chemical found in some plastics, was associated with an increased risk of early puberty in girls [34]. Moreover, exposure to BPA from various sources during pregnancy can potentially result in abnormal fetal growth, particularly when the exposure occurs during the first half of pregnancy [35]. In addition to reproductive issues, exposure to plastic chemicals can also cause metabolic problems. These include obesity, diabetes, and heart disease. For instance, another study in Environmental Health Perspectives associated BPA exposure with an increased risk of obesity in children [36]. Furthermore, certain plastics can release chemicals known to cause cancer. Phthalates and dioxins are among these chemicals. A study in the journal Cancer Epidemiology, Biomarkers & Prevention found that women with high levels of phthalates in their bodies were more likely to develop breast cancer [37]. Lastly, some plastic chemicals can have detrimental effects on the nervous system. This can lead to learning and behavioral problems and even autism. A study published in the journal Neurotoxicology and Teratology found that phthalate exposure was associated with an increased risk of autism spectrum disorder in children [38].

### *3.4. Connecting Health Impacts to Circularity*

Once the potential health impacts have been identified, the next challenge is to determine how these impacts can be linked to product circularity. This can be done in two ways: for workers and for consumers.

#### *3.4.1. Worker Health Aspects:*

In the process of quantifying product circularity, it's essential to consider worker safety regulations, facilities, fire safety, and health insurance. These aspects should be addressed in a way that enhances the circularity score. Establishing a correlation between worker health impacts and circularity involves several steps. Firstly, a comprehensive inspection of the production process is necessary to identify both direct and potential risks to workers. If the process involves the use or production of chemicals harmful to human health, a Control of Substances Hazardous to Health (COSHH) assessment may be required. This assessment should identify how workers could be exposed to these chemicals, such as through inhalation or skin absorption, and the potential adverse effects of such exposure. Next, interviewing all workers is crucial to determine if they have experienced any long-term or short-term health problems since they began working on a particular product. This step helps in understanding the real-world impact of the production process on worker health. Then, cross-referencing the information gathered from the production inspection and worker interviews can help identify which production risks are causing health problems. This step is vital in pinpointing the exact causes of health issues among workers. Finally, it's important to take steps to remove or mitigate the identified risks. Process Systems Engineering (PSE) can be used to identify feasible alternatives that reduce these risks. This not only improves worker health but also contributes positively to the product's circularity score.

#### *3.4.2. Consumer Health Aspects:*

The assessment of health effects on consumers is relatively difficult for several reasons. All companies do not keep a track of the consumers after selling products. Consumers too, generally don't scrutinize and link any subtle health impacts to the usage of a product. Hence, they might be in the dark about the effects they are facing from the extended use of a particular product. Further, the consumers aren't always willing to spend time and effort for such researches. This challenging part can be accomplished through the following ways:

At first, cradle to grave life cycle assessment (LCA) of the target product is to be done, specially focusing on the life span of the product at the consumer's end including any recycle and reuse. For the product, the change of strength, elasticity, the possibility of leaching micro particles from products etc. should be investigated. Then, a large number of consumers of the product are to be interviewed to find out any long term and short-term health anomalies which have started after starting to use that product. From the life cycle assessment and interview of consumers, cross linking is to be done to find which risk of the product is imparting anomalies on consumers. Next, all the found results should be included in product circularity in such a way that lesser the health impact on users, greater the circularity score. Finally, the industry should take steps to remove or mitigate those identified risks. In addition, process systems engineering (PSE) should be directed towards the feasible al-ternatives that reduce those risks.

## 4. Conclusion

According to the Ellen MacArthur Foundation, a circular economy is characterized as a systematic approach to economic development that seeks to substitute the conventional linear paradigm of "take-make-waste" with a more cyclic alternative. The concept of a circular economy revolves around the principle of maximizing the utilization of materials and products, while simultaneously minimizing or eradicating waste. This approach is beneficial for businesses, society, and the environment [39] (pp. 24-25). As a result, the circular economy offers sustainability in terms of economic and environmental considerations. But if the health impacts are totally discarded from circularity, there remains a risk of promoting such a product that can potentially affect the health of the workers and consumers, yet has high rating of circularity. The environmental impact assessment alone can't always guarantee health safety. Therefore, health aspects must be incorporated to the concept of circular economy and direct PSE accordingly.

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