Circular Waste Systems for Urban Resilience:

The Dangers of Linear Waste Systems and how Circular Models Address Those Needs

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Introduction

Despite renewed forces on resiliency and sustainability from governments around the world, rampant pollution and overuse of our natural resources contribute to the climate crisis that threatens our world. Yet economically, we continue to use a linear system of production. In the global "Linear Economy" resources are extracted from the environment, go through several steps of production, then are used and disposed of. While 80% of goods produced in the EU having pre-determined environmental impacts, the linear model or resource harvesting, use and disposal does not create an incentive for many companies or municipalities to reduce waste (European Commision, 2020).

A popular concept that has emerged in sustainability circles is that of the "Circular Economy" where waste is reused as raw material (European Commision, 2020). While the idea is similar in concept to recycling, its scope is meant to encompass materials beyond only plastics, metals and paper. Effective wastewater management, composting, and reusable materials are meant to work in tandem to create a more sustainable future. To make this happen, circular waste systems become the building blocks to the new economy, as governments look to replace their old systems of waste disposal with new techniques of recirculating material back into the beginning stages of production.

Given the existential nature of this threat, examining circular waste systems becomes critical for fighting the climate crisis as well as preserving and replenishing the earth's natural resources. This article discusses the negative implications of our linear waste system, particularly in how it contaminates the environment and drains resources. In the second half it will highlight how linear circular waste systems address these needs and conclude with specific examples of solutions that embody this system of waste management and reduction.

Linear Waste Systems and Environmental Contamination

The need for circular waste management systems can be made abundantly clear by examining the current status quo of linear systems. Unlike circular systems which seek to reuse the waste of production cycles as input materials, linear systems seek to dispose of waste. The result is a widespread use of landfills where municipal solid waste, often unsorted plastics and metals, is left to decompose or rot. Research published by Chemistry and Ecology showed that liquid near landfills in Nigeria contained up to 1.55 mg/L of arsenic and 2.2 mg/L of lead, significantly higher than safe drinking water limits (Oketola & Okpotu, 2015).Unfortunately, these toxins do not degrade and can linger in dumpsites for around 150 years, creating a lasting effect on the nearby water supplies and soil (Adelopo et al., 2018).

Landfills are particularly hazardous in developing countries such as Nigeria, which lack the resources for burry and sealed landfills. Instead, open air landfills or "dumpsites" are the most common form of waste disposal throughout countries is South America, Africa, and Southeast Asia. (Vaccari et al, 2018). Located near urban centers, they commonly produce leachate, or the liquid that forms as a biproduct of decomposing unnatural material. As a result, leachate contains heavy metals such as arsenic and lead, as well as cadmium, copper, nickel and zinc.

This exposure creates a large risk for those living near the areas of the dumpsite. Evidence collected from dumpsites in Nigeria, Sri Lanka, and India shows that adults living as far as 600 m away and children living 400 meters away are at risk for significant carcinogenic exposure (Vaccari et al., 2018). The dumpsites that this study used were also located near significant population centers. Three of the dumpsites: Olusosun, Solous 2, and Solous 3 were in Lagos, Nigeria, the country's largest city with a population estimated between 16 and 21 million people.

Contaminated drinking water, combined with already crowded urban centers creates a breeding ground for health concerns in the population centers of the developing world. This was particularly true during the COVID-19 pandemic, where dumpsites were a breeding ground for the continued spread of the deadly virus, in a study of 30 Brazilian cities, it was reported that 35% of medical waste was not properly disposed up (Urban & Nakada 2021).

Defenders of the current waste management system could argue that the issue in these examples is a lack of funding as opposed to the overall system. Countries like the United States for example have found ways to reduce waste through safer disposal techniques. Yet this ignores the reality that the climate crisis is most dangerous for those in developing countries. These cities, states and countries need to be equipped with a new cost-effective model of waste disposal that prioritizes the safety of their citizens.

Linear Waste Systems and Resource Degradation

A stark truth to basic economics is that we live in a world of finite nature of our resources. Yet our economic system prioritizes infinite growth and the continual expansion of wealth. In a linear economy, waste treatment and renewal become a lower priority for municipalities and businesses, who become far more interested in taping new resources and expanding supply chains. This is because the linear economy fails to see the value of reusing resources as a means of sustainability. With a resource like water, which is naturally cyclical, this view has dire consequences.

Evidence from South Africa suggests that poor wastewater treatment has a direct negative effect on surrounding bodies of water nearby. When examining four wastewater treatment plants, receiving bodies had dissolved oxygen (DO) levels ranging from 3.26 to 4.57 mg/l, which falls below the EU guidelines for healthy aquatic systems of 5mg/l. While Orthophosphate levels ranged from 3.70 to 11.58 mg/l, contributing to the eutrophic conditions which promote algal blooms (Momba et al, 2006). The bodies of waters impacted at these sites include the Tyume and Kat rivers, which act as tributaries of the Great Fish River and bodies of water near the Nahoon Beach and Tembisa Dam. All these sites serve as vital to the South African ecosystem, and are used by humans for fishing, recreation, and consumption. Polluting these waters actively decreases the number of available resources, and contributing to a dangerous feedback loop that only encourages more use and abuse.

As climate change has increased the number of severe droughts worldwide, poor waste wastewater treatment and the increased water use worldwide harms climate resiliency. Evidence from Romania suggests that significant water stress was placed upon the country during dry years. Using the Water Exploitation Index (WEI), which refers to water abstraction as percentage of the freshwater resource, dry years experienced WEI values as high as 32.5% [ML1] in the year 2000. Additionally, 65% of the time, moderate water pressure was observed (Mihai & Minea, 2021). With such a large and continually sustained drain on the water system, the study predicts that climate change will only exacerbate the issue further.

The effects of the linear economy can also be seen in deforestation. Industries such as agriculture, logging, and infrastructure prioritize short-term economic gains over sustainable resource management. In regions like the Amazon, large-scale deforestation is fueled by the demand for commodities like soy, beef, and timber, which are produced with minimal regard for ecological regeneration. According to evidence from the Amazon Rainforest, the destruction of forest cover alters regional climate patterns by reducing evapotranspiration, which in turn decreases precipitation levels in downwind regions by up to 20% during the dry season. This creates a feedback loop where drier conditions make forests more vulnerable to fires and further degradation, reinforcing the destructive nature of the linear economy (Zemp et al, 2017). This unsustainable model ultimately destabilizes ecosystems, making it clear that the linear economy is a fundamental driver of deforestation and its cascading environmental consequences.

Circular Waste Systems and Reduced Environmental Contamination

We will now shift our focus to how circular waste systems address the issues created by our linear economy. The most primary example of circular waste systems comes in the form of recycling. While the linear economy's model of waste disposal seeks to rid itself of waste, recycling re-uses materials such as plastic, metals, and papers which would otherwise be thrown away, and uses them to create new products. While recycling has been a mainstay of positive environmental action, it is worth examining how much recycling has reduced environmental pollution.

Research done in Taipe City, Taiwan, quantifies GHG emissions from different methods of waste treatment, the results were that recycling contributed −24,440.74 MTCE[ML2] . Making it the most effective way of reducing greenhouse gases compared to swine feeding, and Landfilling, which were all found to contribute positive MTCE. The total MTCE was negative because recycling reduced the demand for energy while also reducing non-energy GHG emissions in the manufacturing process. (Chen & Fin, 2007). Taipe City can especially benefit from these reductions in GHG emissions, as it is in a part of the world that suffers from air pollution. With fewer hazardous materials contaminating the air, fewer adverse health risks are exposed to the population than in other cities in east Asia.

While the results from the study are from a more economically prosperous city such as Taipe, Circular waste systems can easily be used in developing countries as well. An analysis done centered around composting in Sri Lanka found that composting would reduce the countries reliance on chemical fertilizers, of which the country imported 160,000 to 227,000 tons between 2005 and 2014 (Bechanov at el, 2018). These fertilizers come at both a high economic and environmental cost to the country, however the composted fertilizer would be generated from the abundant organic waste generated in both urban and rural areas. Thus, saving the country around $191 million in waste management and fertilizer costs (Bechanov at el, 2018).

Circular waste systems and decreased use of/replenishing natural resources
Circular waste systems not only serve to reduce the presence of harmful pollutants in the environment but primarily aim at replenishing the natural resources that we take out of the earth. Agroforestry, for example, operates as a circular waste system by utilizing organic biomass waste from agricultural and forestry activities as a renewable resource, reducing dependency on fossil fuels and minimizing environmental waste.

Agroforestry biomass, such as pruning residues from vineyards and kiwi plantations, as well as scrub and forest pruning, represents an underutilized resource with high potential for bioenergy production. Instead of discarding these organic residues or allowing them to decompose inefficiently, they can be collected, processed, and converted into biofuels through thermochemical methods like micro cogeneration, which achieves a 97% overall efficiency in energy recovery (Torreiro et al., 2020). This system ensures that biomass waste is recirculated within the agricultural ecosystem, reducing environmental burdens like landfill waste, methane emissions, and soil degradation. By maintaining nutrient cycling and organic matter input into the soil, agroforestry promotes long-term sustainability while optimizing land use.

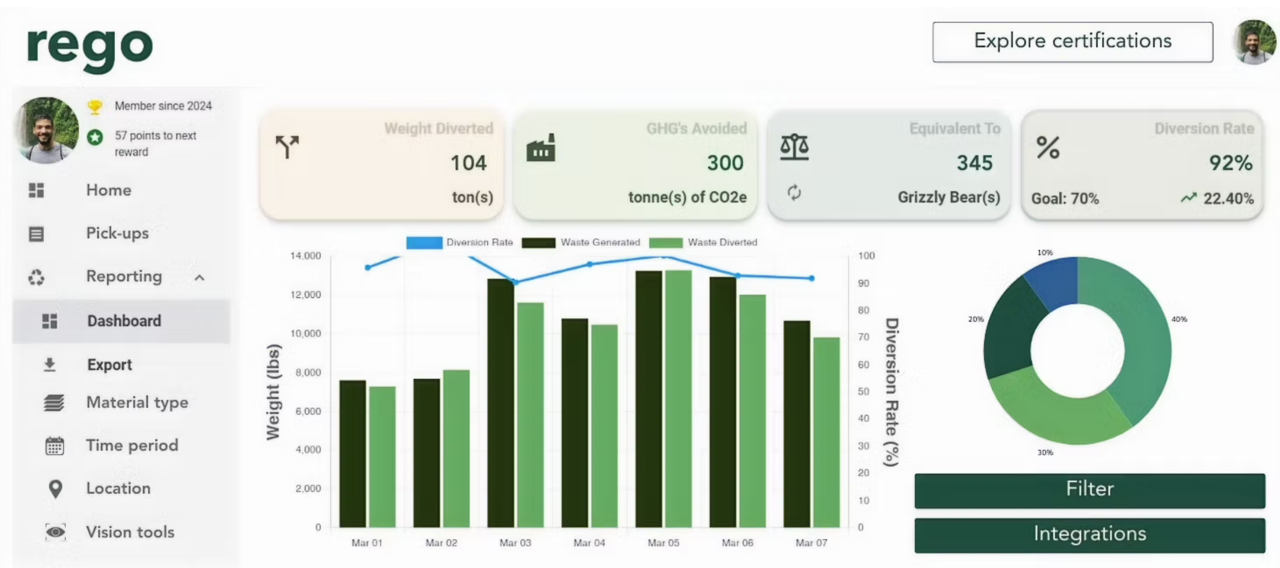
Returning to the example of Wastewater treatment, evidence from Singapore has shown the value of investing into wastewater treatment as an aspect of the circular economy. The country's strategy for water self-sufficiency is built around the Four National Taps, which include local catchment water, imported water, NEWater (recycled wastewater), and desalinated water (Xi & Poh, 2013). Among these, NEWater is Singapore's most innovative water reclamation system, where municipal wastewater is extensively treated using microfiltration, reverse osmosis, and ultraviolet disinfection to produce high-quality water that meets both industrial and potable water standards. The reclaimed wastewater system significantly contributes to replenishing usable water and enhances

Singapore's resilience to climate change and water scarcity. The study finds that without proactive investments in water recycling and desalination, Singapore would face severe water shortages by the 2030s due to rising demand from rapid population and economic growth (Xi & Poh, 2013).

Investments in NEWater infrastructure have allowed Singapore to meet up to 40% of its current water demand, with projections to reach 55% by 2060 (Xi & Poh, 2013). This transition has also reduced pressure on natural freshwater resources, as less groundwater extraction and reservoir expansion are needed. Moreover, by reusing treated wastewater instead of relying on new water sources, Singapore has reduced energy consumption and carbon emissions associated with conventional water sourcing. The research underscores that a comprehensive water recycling system is essential for urban water sustainability, ensuring that every drop is reclaimed, purified, and reintegrated into the supply chain, making Singapore a global leader in circular water management.

Innovative Solutions Addressing These Challenges

Moving towards circular systems is critical for reducing pollution in the environment and replenishing our finite natural resources. While this article has highlighted examples of circular waste systems in cities such as Taipei City and Singapore, much of the world still operates with linear waste systems. Leading Cities is committed to being part of the change that moves us towards a circular economy by supporting technologies that aid circular waste systems by promoting the following solutions.



Rego: Data-driven waste audit platform designed to help cities and municipalities efficiently track and manage waste, contributing to a circular waste system by enabling better waste diversion, recycling, and resource recovery. Unlike traditional waste audits, which require manual sorting and time-consuming analysis, Rego captures real-time waste data using photo-based and container-based audits, instantly integrating the information into waste data dashboards for analysis. This approach allows cities to identify waste composition trends, improve waste reduction strategies, and divert materials from landfills by making informed decisions about recycling, composting, and repurposing waste streams. By closing the gap in waste data collection, Rego not only helps municipalities optimize waste management costs but also supports compliance with environmental regulations and certifications, contributing to a sustainable and circular waste economy where materials are continually reused rather than discarded.

Carbotura: Advanced waste processing company that integrates proprietary technologies to convert waste into valuable resources, eliminating the need for landfills and promoting a circular waste system. Their innovative processes include Exogenesis™, which transforms landfills into resource recovery sites, and Regenesis™, which recovers materials at the molecular level for reintegration into manufacturing. Additionally, their Pregenesis™ process stabilizes municipal solid waste to prevent greenhouse gas emissions before it undergoes further refinement. By shredding, sorting, and converting waste into reusable raw materials, Carbotura ensures that resources are continuously cycled through industries, significantly reducing environmental impact, lowering carbon emissions, and decreasing reliance on virgin materials. Through these cutting-edge solutions, Carbotura supports a zero-waste, zero-emission future, aligning with sustainable waste management practices and the principles of a circular economy.

Eagleridge: Advances circular waste systems through its MicroPoP technology, which optimizes wastewater treatment by converting waste-activated sludge (WAS) into biogas and recoverable nutrients. Traditionally, WAS is difficult to manage due to its high moisture content, poor dewatering properties, and slow digestion, resulting in high disposal and incineration costs. MicroPoP solves this by breaking down WAS cell walls, making organic material more accessible for microbial digestion, leading to a 100% conversion of WAS into biogas. This not only eliminates sludge disposal but also significantly reduces greenhouse gas (GHG) emissions and operational costs. Additionally, Eagleridge's MagPi technology facilitates phosphorus recovery from wastewater, producing a useful fertilizer product while ensuring regulatory compliance for phosphorus discharge. Together, these innovations turn waste into valuable resources, minimize landfill reliance, and create a closed-loop wastewater treatment system, demonstrating how wastewater can be transformed into a sustainable, revenue-generating resource rather than an environmental burden.

ECOSTP: Net-zero sewage treatment technology inspired by the digestive processes of a cow's stomach, utilizing biomimicry to treat sewage in a decentralized, self-sustaining manner without the need for power, chemicals, or human intervention. This innovative approach involves underground chambers where microorganisms break down waste, effectively mimicking natural biological processes. By treating sewage on-site and converting it into non-polluting effluent, ECOSTP significantly reduces the environmental footprint associated with traditional sewage treatment methods. This process not only conserves energy but also eliminates the need for chemical additives, aligning with the principles of a circular waste system by transforming waste into a resource and promoting sustainability.

ReallyRecycle:[ML3] An innovative "Scan-to-Collect" system that streamlines recycling by allowing users to schedule waste collection simply by scanning a QR code on their recycling bags. This approach ensures that recyclable materials, particularly plastics, are efficiently collected, sorted, and reintegrated into manufacturing processes, reducing landfill waste and promoting a circular economy. Their system also encourages consumer participation in responsible waste management by making recycling more accessible and convenient. Additionally, each bag used contributes to natural rewilding projects, further reinforcing the company's commitment to sustainability. By combining technology-driven waste collection with environmental restoration, ReallyRecycle helps close the loop on material use, ensuring that waste is continuously repurposed rather than discarded.

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