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Perspective

Responsible Materials Stewardship: Rethinking Waste Management Globally in Consideration of Social and Ecological Externalities and Increasing Waste Generation

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Abstract

Unsustainable material extraction, use and disposal - the 'take-make-waste' model - places communities globally in a state of social inequalities and environmental conflict (the slow violence of polluting the air, water, and soil we all depend). Current waste management practices are designed for efficiency of disposal but do not address increasing waste generation and waste externalities. The present global waste situation is magnified by exponential increases in plastic production; misconceptions of recycling; and confusion with 21st Century materials. Addressing these imbalances requires cities to have a new understanding of waste-making processes and practices, reconceptualized as responsible materials stewardship. Responsible materials stewardship is an integrative new system for 're-evaluating-re-designing-restoring,' in line with circular economy, and designed for resource monitoring; overall waste minimization and recovery; reducing materials of harm; and supporting production and use of materials that steward ecological regeneration.

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Keywords
Waste management; sustainability; plastic pollution; responsible production and consumption; circular economy; resource recovery; environmental justice; social ecology

1. Introduction

Globally, the patterns of linear materials consumption have resulted in the use of 1.75 times more resources than the earth's regeneration capacity [1]. In the past 50 years, more resources have been consumed than in all of human history [2]. However, these excesses do not come without cost. The externality of current consumption cycles is waste. The rate and volume of how a society uses, discards, replenishes, and values materials indicates the capacity for long-term social equity and overarching socio-environmental sustainability [1-5]. Current business-as-usual scenarios show waste generation rising, not falling, by nearly 60% or even greater in the coming decades [6]. This reflects dire imbalances with material use, and ultimately this unsustainable material use and subsequent waste generation place communities in a state of environmental conflict [7, 8]. Current waste management scenarios do not address this imbalance with waste generation, as the status quo waste management practices perpetuate the linear 'take-make-waste' waste management model. The perverse nature of the prevailing system is shown through numerous paradoxes: increasing waste for society actually increases GDP, as this means more spent to manage this waste and increasing medical expenses due to exposure to those living near or working at waste sites. As well, increasing waste for waste managers is beneficial as it gives them more business; haulers get paid to haul more waste; landowners get paid for land; and politicians can take kickbacks from large contracts. When a system exhibits signs of being broken but persists, it is a sign that there is vested interest by certain parties to maintain the status quo.

2. Background

In recent decades, the amount of waste generation has more than doubled [9], and in 2020, globally, around 2.24 billion tons of solid waste were generated [10]. Given increasing urbanization and shifting consumption norms, by 2050 this amount is projected to increase by 73% to 3.88 billion tonnes of waste generated (ibid.). Waste generation is not a stand-alone issue, however; waste making connects broad-spectrum to all social processes, especially within the contexts of: urbanization and development; urban planning and land management; GHG emissions; labor; social equity; public health; rural-to-urban migration; increasing population; increasing consumption; and other factors that arise in tandem with the global, urban-dwelling majority [9, 10]. Yet, municipal solid waste management - as defined by current parameters - is narrow and decidedly centered around engineering principles of storage, collection, transportation, processing, and disposal. In current, linear waste management systems, most of the generated waste material ends up in landfills or is incinerated, even with the existing rhetoric of recycling and segregation. However, if redesigned with dedicated reduction and recovery systems, this waste can be minimized, collected, turned back into resources, and have much less impact on the planet [11-14].

Waste making is a symptom of complex global production processes, with impacts that fall on the local civic population and ultimately the local environment. MacBride [15] remarks on these processes, "Garbage is the material artifact of a great range of steps prior to wasting. Its existence signals larger, more diffuse problems. In it, we see the last vestige of havoc wreaked by materials as they flow globally"[15]. 'Distancing' is the key assumption that underlies all current linear waste management plans. Clapp [16] defines distancing as geographical and mental space put between consumers and waste; a case of rearranging social and ecological harms across geographies and timeframes. To move waste away from a given local context results in gaps in the political and social capability to address harms created as a result of the waste making processes [16-19]. Distancing removes the transparency in waste processes, and allows the majority of people to remain oblivious to the consequences of the proliferation of the wasting of materials. Rather than think of waste as a static noun; it is helpful to reframe the practice into a verb, where the practice of wasting is seen to take on a range of characteristics dependent on social norms and practices.

One thing that all developed and developing urban areas have in common is an excess of plastic waste. Every year, globally, plastic producers make over 400 Mt of plastic, and collectively 300 Mt of plastic is disposed of each year [20, 21]. Currently, approximately 50% of global plastic production goes into single-use packaging [22]. Although exceedingly difficult to calculate, of this plastic packaging that is wasted, annually 40% of plastics are sent to landfills; 32% is leaked directly into the environment; 14% incinerated and/or are used for energy recovery; and 14% is collected for recycling, but of this only 2% is truly recycled (through a one-for-one recycling), with 8% downcycled and 4% lost in the production process [23]. This is the best estimate of the damage that we have at the moment. With more plastic transparency in business - especially if new rules are passed through a UN Global Plastics Treaty- then plastic leakage will be more accurately reflected. Since the beginning of the single-use, convenience culture [24], the practice of wasting has resulted in distancing modern society further from states of sustainability. Even the most 'managed' waste system in developed countries creates externalities. Moreover, the pollution from plastic starts not when it becomes discarded waste, but is interwoven with the entire process of plastic use. Pollution starts at extraction, during production, during transportation, during use (leaching of chemicals and microplastics), and when plastic is thrown away - and the fossil fuels in extraction, production and transportation are fundamentally linked to climate change [25-27].

Global plastic production continues to increase at an exponential pace [20], and by 2050 plastic production could account for 20% of global oil production [22]. Most of this plastic pollution burden falls on Asia [28, 29]. In a survey of waste management in the global south literature, every case cites environmental contamination at waste sites as a result of lack of management, including air contamination, ground and surface water contamination, and disease vectors. However, the majority of the waste in the global south literature addresses the fact that waste management systems are *insufficient* [9, 30-33]; yet, the proposed solutions are predominantly within the status quo, linear, engineered waste management model, which does not question the current, unsustainable trajectory of increasing waste generation.

Considering international norms, waste management as currently practiced violates the fundamental right of everyone to a clean, healthy, and sustainable environment, as proclaimed by the United Nations [34]. People who live in neighborhoods adjacent to waste sites (landfill, incinerators, recycling facilities, and other waste sites) are more prone to chronic sickness and other health hazards [35]; the sites also wreak havoc on the local environment, polluting air with waste burning, flares and methane [36]; polluting soil and water through leaching contaminants [37]: and endangering local wildlife that scavenge from these waste sites, such as the infamous elephants on waste dumpsites in Sri Lanka [38]. Linear waste management practices are also a threat to the United Nations Sustainable Development Goals (SDGs):

- SDG #6: Clean Water and Sanitation, through polluted groundwater;
- SDG #10: Reduced Inequalities, as populations living or working in landfill and dumping zones are blighted with pollution and marginalization;
- SDG #11 Sustainable Cities & Communities, as waste is increasing in urban areas, coupled with glaring externalities;
- SDG #12: Responsible Consumption & Production, as current design wastes material, promotes overconsumption, and doesn't design systems for recovery of materials, such as precious rare earth metals in e-waste;
- SDG #13 Climate Action, through methane emissions from waste; carbon emissions from plastic production, through the transportation of waste;
- SDG #14 Life Below Water, through leachate running into waterways; waste dumped into the ocean and waterways;
- SDG #15 Life on Land, through increasing land used for dumpsites and waste processing; landfills and pollution encroaching on habitats; impacts on wildlife;
- SDG #17, Partnerships for the Goals, by lack of coordination for meaningful waste reduction [39].

Waste is a social issue (generated by people and cultural norms) that requires social responses in order to move beyond the current engineered, linear waste management practices [11]. And, the increasing rates of plastic generation is truly a global challenge – relevant for both global north and south contexts – and these challenges require local-appropriate solutions [40, 41]. Designing a better or 'more efficient' linear solid waste management system for the current realities of waste generation will only result in a continued, unsustainable waste systems (ibid; [13, 14, 42]). More efficiently disposing of waste without questioning the very nature of waste in the first place, is the thinking that led us into the collective, global waste generation crisis.

3. Problems with Linear Waste Management & 21st Century Materials

3.1 Challenges with Linear Waste Management Models

The idea of management implies a continuation, that a system is in place. But, what kind of system is it? To manage for the *status quo* of the current waste situation means to allow and perpetuate the continuation of current linear waste practices; thus support increasing waste generation. Yet, already globally countries face a crisis around waste management [6]. Waste in developed countries is just further 'distanced' so that the effects are not seen by the people who create it [16]. Increasingly environmental justice claims are being made by those in the global south who protest that it is not right for global south countries - already struggling with their own waste issues - to have to simultaneously deal with the waste of the global north [43]. Thus, to say waste is 'managed' requires the follow-up question: managed for whom and for what? Waste management as practiced currently takes an anthropocentric, economic expediency lens on materials, defined by economic means, which is not a beneficial process viewed from an environmental, interspecies, or even a collective, social lens.

The linear waste management system is not working, not even in developed countries [11, 13, 14, 40-42, 44, 45]. Continued management frameworks will result in the same systems repeating and recreating itself - more transportation, more land degradation, more materials to manage ad infinitum. Addressing the issue requires both upstream (i.e. pre-consumer redesign, plastic substitution) and downstream (i.e. post-consumer recovery, reuse) solutions, as well as a far greater scale of action compared to efforts thus far (e.g. banning certain items like straws or plastic shopping bags is helpful, yet not enough) [46].

Waste is one of the primary human links to the environment yet currently waste operates as one of the points of greatest imbalance. Like a healthy forest that recovers and recirculates all material, waste could be one of the ways that human society becomes in balance, circular, and sustainable with the natural world. If materials are designed as resources rather than waste, then nothing needs to be wasted, just like in a forest. The most promising systems are those that have been redesigned at the local level, with local needs and considerations in mind, such as the zero waste practices instilled in the village of Kamikatsu, Japan [11]; the neighborhood-level materials recovery facilities implemented in Manila [41, 47]; or village level waste collection as seen at TIEEDI in Darjeeling, India or Project Tsangda in Ladakh [48]. Rather than exclude citizens from the waste processes, both of these models depend on local support and have communities fully involved in order to reduce and streamline material streams.

3.2 Plastic as a Material of Caution

Current waste management models were designed for materials of the 19th Century, not the 21st Century. To move away from economies of waste harm requires reconceptualizing our relationship to plastic. The rapid rise of this material after WWII was due to its flexible, convenient, applicable nature [15]. Yet, a reframing of this material is needed to incorporate the multidimensional harm it has shown to generate over the last several decades, as scientists as well as the general public are seeing the impacts more clearly. Plastics are: a toxic and hazardous material [49]; an ecological liability [50]; a generator of endocrine disruption and other health impacts in humans [25, 51-55]; a problem of the fossil fuel and plastic industry [40, 56, 57]; a material that signifies a lack of creativity, not redesigned on the behalf of the environment or society [17]; a killer of wildlife [58]; and the cause of microplastics in the oceans [59-61]. To hold a single plastic wrapper, one can imagine the whole chain of events, across multiple geographies, populations, and domains resulting from its creation – a process high in carbon outputs [26] and coupled with leaching chemicals [49, 62, 63]. As a result of the pervasive social and ecological damage created by plastics, calls have been made to classify plastic as a hazardous material [64], and also for an international treaty banning single-use plastics [65].

In 2018, the Basel Convention, which regulates the flow of hazardous waste worldwide, initiated a first step and amended the convention specifically for plastics, to put more regulations on global plastic waste trade flows, in order to keep plastics out of the environment [66]. Similarly, the International Negotiating Committee is working on a legally binding resolution for plastic pollution [67]. However, addressing the harms of plastic has not yet translated into stopping this material at its source [40, 57], and plastics production is still projected to increase exponentially in the coming decades [20].

Already, studies reveal that microplastics can be found in rain [68, 69]; atmospheric deposits [70]; in the deepest ocean trenches [71]; above the 8000 m level on Everest [72]; impacting marine environments [73, 74]; embedded in arctic ice [75]; drinking water [76]; in fruits and vegetables [77, 78]; as billions of pieces flowing out of principle rivers like the Ganges daily [79]; circulating in human blood [80]; consumed by humans [81]; in human placentas [82]; and researchers suggest that soon we will observe it passing the blood-brain barrier in humans (already observed in mice) [83]. Yet, until recently, researchers have been timid about calling for reduction of production to reduce plastic pollution [84]; although there are emerging calls [85], including current pressure by especially global south groups working to influence the UN Plastics Treaty [86]. How much longer will it take to condemn the everyday common usage of this material so damaging to human and environmental health?

3.3 All Recycling Is Not Equal

Waste management has gone in the wrong direction. The 3R concept (reduce, reuse, recycle) has been around for decades, but yet, globally waste generation is not reducing but increasing [7]. The trend has been for an increased push for the last of the three R's, recycling, which does not minimize materials consumption use, nor has shown to be effective for managing plastics [23]. Effective recycling as a strategy to minimize resource extraction footprints (keeping materials in circulation) requires differentiation between materials – i.e. glass, paper, aluminum, plastic - and their various recovery processes and lifetimes. Material like glass and aluminum can be converted one-for-one in the recycling process, are nearly infinitely recyclable; and thus, if recovered and processed locally, save considerable amounts of energy, transportation, and raw materials in these processes. However, in materials life cycle analysis (LCA) calculations, plastics often are ranked as better than other materials, because LCAs do not consider long term externalities (e.g. environmental contamination by microplastics) [87]. Plastics, on the other hand (of the small fraction 'recycled'), are predominantly downcycled, and in this process virgin plastic additions are required. The recycling percentage of plastic sits at an abysmal 9%, with 2% fully recycled (1:1); and the vast majority of material either dumped in the environment or not collected [23]. Moreover, plastic recycling sites are shown to be hotspots for microplastic pollution [88]. Further, after plastic is downcycled once, most likely it will end in the waste stream after its second (usually short) lifecycle. Thus, if plastic is only recycled twice, for instance, this means it still has a short usage lifetime, and a decades-long time to remain in the landfill. Plastic industry representatives have even said that recycling was never meant to be a solution to plastics, as they want to continue producing the material [89].

Pathways to enable recycling are also problematic, as having the *means* to recycle is important for recyclability. If a material is packaged as 'recyclable' but there are no recycling options in that area, the 'recyclable' label is an empty promise. This applies to both global south countries without recycling infrastructure, as well as global north contexts without the recycling infrastructure, that depend on exporting material. The potential for the material to be recycled (labelling) does not equate materials actually being recycled [46]. This gap is deceptive, because it leads the public to think there are responsible pathways for materials, when really this is a 'wishcycling' on the part of the producers. The term 'wishful recycling' applies to consumers that throw items in the bin hoping they will get recycled - whether or not an actual pathway exists to recycle that material in the municipal waste stream. However, before the blame is directed at the general public, there is also a 'wishful recycling/composting/recovery' on the part of businesses that assume cities will pay for the infrastructure needed to process their materials, whether this be a recycling facility, an industrial composter, the training required to recover materials (i.e. from e-waste, appliances), a large recovery facility for materials, and so forth.

Disruptive to environmental justice, recycling in the global north predominantly consists of sending material thousands of miles overseas for processing, creating a large transportation carbon footprints, as well as sending material to locations with questionable social and environmental safeguards in place. High-income countries export approximately 70% of their plastic waste [28]. Before China's 2018 National Sword policy on recycling imports, 45% of this plastic waste was sent to China alone (ibid), and now this waste is being displaced to low-income countries predominantly in Asia and Africa [90]. Documentaries such as Jiuliang Wang's Plastic China [91] and Deia Schlosberg's The Story of Plastic [92] highlight these discrepancies between recycling promises and on-the-ground actualities. 'Distancing' recyclable material overseas means a lack of accountability and transparency of processes, as it is nearly impossible to know the human conditions and environmental conditions of the processing of this material. Traced containers from the UK, for instance, show they are illegally dumped in Turkey, Malaysia and other less-regulated locations [93].

Ultimately, recycling should be done locally with transparency, to reduce the global displacement of materials; to account for the environmental and social justice issues of waste (also known as "waste colonialism" [94]); and maintain more resources for local use. Rethinking processes of recycling could also be considered means for addressing 'metabolic rift,' as nutrient cycles and materials are displaced around the globe [95, 96]. A geographical and time range could be added for sustainable recycling, for instance: material responsibly reprocessed within 100 miles, that can be recycled at least 100 times.

3.4 Caution with Emergent Materials

In the rush to fill opportunities in the market, businesses propose many greenwashing solutions related to alternatives to plastic. In the wake of plastic bag bans, the void of 'what material to use' has been filled with many products claiming to be 'compostable' and 'biodegradable' [97]. Yet, many of these products still contain plastic components, including enzymes that help the plastic composite material break down faster [98]. However, it is well established that as plastics break down they do not disappear but create micro and nanoplastic [99]. Knowing this forces us to re-examine claims that such material is worth pursuing as a viable alternative. 'Biodegradable' product labelling confuses the consumers as well as policymakers, and the public uses these products without realizing the full environmental footprint. Plastics can also be designed to look like fabric, such as with oxo-biodegradable plastic bags, and similarly consumers do not realize that they are continuing to support the plastic economy.

Compostable material is also often problematic. For instance, most bio-based, compostable material requires an industrial composting facility to be processed [100], yet in most municipalities such machines do not exist, especially in the global south. Also, a separative collection system is required leading to increasing complexity. Furthermore, recyclers do not want biodegradable or compostable plastics because it "pollutes" their potentially recyclable materials streams. In one study attempting to compost bags at home, the compostable bags were buried for three years and then dug up [101]. After 3 years, the bags were found to still be able to hold a full load of groceries, thus negligible composting of the material had occurred.

Current labelling of materials is not universally standard. Even the EU with more stringent laws has a looseness in terminology where bioplastics can mean bio-based, biodegradable, or both [102]. The EU thus acknowledges that, "Given that these have very different properties, consumers could misunderstand the rather vague term 'bioplastics'" (Ibid.). If material is going to be labelled as compostable, it should truly be an organic material compostable in natural conditions. Similarly, if material is labelled as biodegradable, it should not consist of plastic derivatives, plasticizers or coatings, and be able to biodegrade without causing other types of pollution.

3.5 A Way Forward: Responsible Materials Stewardship for Sustainable Cities

Thinking beyond linear waste management means thinking beyond materials as 'waste.' Population censuses are used to determine what kinds of services and resources are needed to maintain a healthy society. Similarly, cities can create a *materials census* to determine the characterization of resources circulating within a given community/city to create a baseline for responsible materials stewardship. The phrase 'you can't manage what you don't measure' has been applied to the waste management economy to manage waste in a linear trajectory; yet, it can equally be applied to the management of waste through a lens of responsible materials stewardship. A comprehensive analysis of materials within the system will help each city understand what kind of impact materials are having within their resources system. Continued linear management frameworks will result in the same systems of negative spirals repeating and recreating themselves- more transportation, more land degradation, more materials to manage ad infinitum. It is time to re-envision the systems for materials flows, in both developed and developing countries. Systems are designed to carry out the tasks given to them [103], so with a redesigned waste system, cities can prevent materials leakages and externalities that too often thwart effective materials management [46] and arrive at a new future of sustainable material use.

Rather than take-make-waste, materials processes can be reconceptualized as Re-evaluate, Re-design, and Restore. Responsible materials stewardship at these three stages is optimally conceptualized at the micro (individual), meso (small-medium business & entities), and macro levels (corporations, city-wide, regional, inter-regional), incorporating both upstream and downstream solutions.

1. Re-evaluate (Take): First, consider the social and ecological impacts of the extraction and use of materials. Is the product being produced ethically and responsibly for long-term social and ecological sustainability?
2. Re-design (Make): How can damaging processes and products be redesigned?
3. Restore (Waste): Rather than negative externalities, how can the processes by which we produce and use materials enable the restoration of ecosystems?

Pertinent in the phase of 'Re-evaluating,' instead of allowing all materials to circulate and then dealing with the externalized impacts later (current practice), employing the *precautionary principle* and stopping the production and use of damaging materials will allow the new system to emerge. Taking local responsibility for waste – the opposite of the distancing of waste - results in confronting the consequences of materials use. Instead of incrementally tweaking the old system to create more attuned processes for distancing materials, materials stewardship is the opposite: figuring out what is being used within the city or community, and keeping these materials in the local economy in order to work productively and responsibly with these resources. Instead of allowing the indiscriminate production and use of materials that are harmful for society, stopping potentially harmful material before it enters circulation in the upstream production phase will save energy, resources, and allow for responsible resource pathways to emerge. In this case, responsible materials stewardship is a way to work within the bounds of nature; provide local, plastic-alternative solutions for packaging; and stewards circular production and distribution. Precautionary principle reduction of exposure to harmful material includes the example of a ban on BPA-type coatings on alternatives to plastics, like biobased food containers.

In another case of Re-evaluate, for instance, Tetra Pak, with multilayer plastic, paper, and aluminium, is a decidedly difficult material to process, requiring specialised machines, that are for the most part absent the world over. Rather than design new systems for this problematic material (e.g. purchasing expensive machinery to process, and necessitating Tetra Pak's continued trajectory of use), this material should be designed out of the system. Designing out harmful materials (e.g. materials produced with high levels of chemicals) also safeguards waste workers who are exposed to this material regularly. Just transitions towards sustainable, long-term materials management incorporates waste pickers into the system, realising that material streams provide livelihoods for many, especially marginalised communities (International Alliance of Waste Pickers, 2023) [104].

If certain materials cannot be used as resources after their first use (i.e. material designed for single-use), this is an opportunity to replace these items with something circular, reusable, and/or regenerative. For instance, bans on plastic bags prompt reuse (personal) as well as alternative delivery models like tiffin food delivery systems (prevalent in urban India), or reusable mailer and shipping options (meso-macro). At the more upstream production phase, although production is incumbent within definitions of circular economy [5, 39, 105], this stage is often overlooked as it goes against current continual production norms. Precious materials such as rare metals enter the urban environment from distant extraction sites around the globe without easy recovery options [106], and even urban mining is costly and many products are not designed to be disassembled and recovered. However, we can find some examples of products that eschew planned obsolescence norms, such as Fairphone (Netherlands) which designs modular phones that can be easily repaired, or the site Buy Me Once (USA) that showcases products that are designed to last a lifetime. Another idea for enabling the 'disruptive innovation' of circular models, is to provide tax breaks for businesses that are pursing circular solutions [107].

On design, once a city knows what materials it is working with through a waste audit, it can begin to design a new system of materials use through partnerships and ongoing research with a materials recovery facility and research center (as described by [42]). Moreover, waste reduction experts and resource recovery leaders can fill the place of waste managers (this is more than just semantics, but a reorientation that focuses on waste reduction rather than more efficient management). A living example of responsible materials stewardship can be seen in the Austin Materials Marketplace (Austin, TX) [108]. This is a multi-pronged program for materials recovery in Austin with the aim to minimise 90% of the waste sent to landfill by the city by 2040. Material that was once going to landfill is now recovered and circulating in the city, adding an additional $1.1 Billion USD to the local economy; 6,300 jobs; and collaborative networks between businesses and corporations, the city, nonprofits, academics, and local citizens (ibid). The Austin model allows for "materials matching," or basically pairing wants and needs between one company's waste stream and another's production line, closing the loop in an effective, local-based, circular economy. The model incorporates micro-level change (e.g. individuals who join fix-it workshops); meso-level (e.g. small business-to-business transactions, and business creation for small material-recovery businesses); and macro-level change (e.g. addressing the city-wide level flows of materials and larger corporate participation with companies like Ford). Thus, the recovery project exemplifies innovation across the value chain to prevent waste leakage into the environment and landfill [46].

The processes of Austin's waste management revisioning include: renaming their waste management department to their Resource Recovery team (no more city waste management); creating an online platform for materials exchange within the greater Austin area; facilitating innovation with materials such as through contests with the local university; and creating an extensive regional ecosystem for materials recovery. Other key partners include the US Chamber of Commerce and the US Council for Sustainable Development (which helped to launch the idea). Because of their successes, the program has been named one of the best circular economy cases in the US [109], and their model has inspired similar materials recovery networks in Turkey, Canada, and other parts of the US.

Responsible materials stewardship is an opportunity for solutions to emerge within the local economy. For instance, a city could support an innovation challenge to steward local solutions (e.g. innovation with waste streams as in Austin), as well as support local innovation in the responsible materials economy (e.g. through municipal construction and purchasing tenders). In the city of Portland Oregon, the Rebuilding Center [110] offers up a vision for how materials recovery and reuse in the building sector can be adopted. Not only can reclaiming building materials through deconstruction rather than demolition keep valuable materials out of landfills, it reduces the need to extract resources (i.e. wood, metals, sand), and thus reduces carbon and materials footprints of the construction industry - an industry that currently contributes 39% to global carbon emissions [111].

For Restore, materials options that can be supported at a city or regional level for designing-out-waste include: packaging from mushrooms or hemp fibers (hemp removes contaminants and benefit soil quality, fix nitrogen and can be grown without chemical fertilizers) (e.g. [112]); hemp stalks for certain kinds of construction (e.g.[113]); building and making with bamboo (e.g. [114]); or for coastal communities, using kelp for packaging (which is beneficial for marine environments, sequesters carbon dioxide, also does not require chemical fertilizers, and is an additional livelihoods generator) (e.g. [115]). Collaborations related to indigenous and local knowledge systems are also key ways for restoring equilibrium between social and ecological systems [116], as well as the understanding of local materials that can be incorporated into a responsible materials economy.

Waste as responsible materials stewardship is a way for cities to take full responsibility for social and ecological externalities, and be able to create systems that work, rather than systems that displace harm on the environment and vulnerable populations. The responsible materials stewardship model - rather than waste management - is also a way for cities to address climate change (reduce landfill methane, and carbon from distancing waste); numerous SDG's (especially numbers 6, 10, 11, 12, 13, 14, 15, and 17); and address concerns of local as well as global environmental and social justice. As such, re-envisioning waste can be coupled with the emergence of revitalizing and redesigning climate smart and equitable global cities for the 21st Century.

4. Conclusion

Increasing waste generation globally - especially plastic waste - requires strategic local action that moves beyond linear waste management, engaging and incorporating micro, meso and macro scales, for upstream and downstream responsible materials stewardship. Current practices to design more efficient, engineered waste management systems do not address the reality of increasing waste generation (especially plastic waste and e-waste); the problems with recycling; the open marketplace of alternatives to plastics; and allow for the continued degradation of the environment as well as compounding chemical impacts on human health. Global north and south countries alike have adopted linear waste management trajectories that will result in further social and environmental harm if not redesigned. For a sustainable future, responsible materials stewardship models that reconceptualize and redesign waste systems for waste minimization are requisite. Re-evaluate, Re-design, and Restore processes, coupled with increasing circular and regenerative materials pathways can ultimately rehabilitate social-ecology relationships of balance rather than relationships of increasing degradation.

Author Contributions

The author did all the research work of this study.

Competing Interests

The authors have declared that no competing interests exist.

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