Circular Economy and Solid Waste

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This document is one of a series of concise papers offering relevant facts and figures, and arguments outlining key benefits of the circular economy to address planetary crises or a sustainable development challenge. It is a knowledge product, part of the toolbox, which members of the Global Alliance on Circular Economy and Resource Efficiency (GACERE) have developed, to support their advocacy at political level and multilateral fora for transitioning towards a circular economy. It is not a negotiated document and as such it does not necessarily represent the views of all GACERE members. Furthermore, it does not, nor is it intended to, create any binding, legal or financial obligations under international or domestic law.

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1. Introduction

The purpose of this paper is to show how the transition to a circular economy can support governments' efforts to deal with the challenges that solid wastes pose to countries' sustainable development as well as to reduce their impact on the triple planetary crises of climate change, biodiversity loss, and pollution. The paper starts by laying out the relationship between material flows in our economies and the quantities of solid waste generated (since another GACERE working paper is focusing on air and water emissions, this paper focuses on solid waste in all its forms). It then considers the drivers and sources of waste generation. Then, using the waste management hierarchy as a guide, the paper describes, with examples from various sectors and different regions of the world, the circular economy practices all along products' lifecycles which can substantially reduce the quantities of solid wastes requiring treatment and disposal, also giving an outline of some of the key policy instruments which governments can deploy to promote these practices. In keeping with the guidance given for the preparation of this paper by GACERE members, the focus is on policies that can be adopted in the early stages of products' lifecycles. The paper finishes with a brief consideration on how innovation can stimulate a circular economy transition. The examples provided are intended solely as an illustration of current possibilities and trends, and should not be construed as an endorsement of any particular manufacturer or practice. It has been attempted to give examples from the different regions of the world (with a stronger focus on the Global South), and for the several priority sectors highlighted by the GACERE members (food systems; packaging; electronics; fashion and textiles; the built environment). It was not possible to verify the different claims made about the performances achieved by adopting the circular economy practices described.

2. Facts and Figures

Most countries collect data on the amounts and types of solid wastes they generate and manage.[1,2,3] However, these data collection programmes do have weaknesses. One major weakness is that many countries only gather data on the solid wastes which are collected in formal waste collection systems. This ignores the solid wastes which are dumped or otherwise abandoned, which can be a large percentage of the solid wastes generated in certain countries. Many of the data sets also focus just on municipal solid wastes and ignore other solid waste streams. The World Bank has recently attempted to give a more detailed snapshot of solid waste generation and management worldwide. The focus of its work is on municipal solid wastes (residential, commercial, and institutional wastes), and it estimated that in 2016 a little over 2 billion tonnes (GT) of these wastes were generated globally, predicting that this will increase to 3.4 GT by 2050. In addition, however, the World Bank has collected data on a number of "special wastes": agricultural waste, construction and demolition waste (CDW), e-waste, hazardous waste, industrial solid waste, and medical waste. Some of these are generated in amounts which are larger to much larger than municipal solid waste. Globally, industrial solid waste generation is almost 18 times greater than municipal solid waste, agricultural waste more than 4.5 times greater, and CDW nearly 2.3 times greater.[4] Another very large solid waste stream which the World Bank does not consider is mining waste, which has been estimated elsewhere as being in the region of 7.4 GT, nearly 4 times larger than municipal solid wastes.[5]

From a circularity point of view, it is more useful to view solid waste generation data through the lens of the overall flows of materials through our economies. This can be done using Material Flow Accounts (MFAs). Circle Economy, among other organizations,[6] has prepared MFAs at the global level.[5,7] It has estimated that in 2020 100.6 GT of materials were processed in our economies worldwide. Of this amount:

- 31.0 GT net were added to economies' long-term stocks in the form of long-lived capital equipment, buildings, and so on. This is equivalent to 30.8% of the total amount processed.
- 32.6 GT (32.4%) became solid waste.
- 14.6 GT (14.5%) were released into the air, water, or other environmental compartments.
- A further 22.4 GT (22.3%) were unaccounted for and assumed to have been dispersed into the environment as emissions and unrecoverable wastes.

Of the solid waste generated, only 8.6 GT (8.5%) were recovered and recycled back to processing operations. This means that 92.0 GT (91.5%) of the materials processed were extracted as virgin raw materials from the environment.[5] These data show that overall, our economies are very linear, with most of the materials which our economies extract from the environment being discarded back into the environment.

A similar picture to that at the global level emerges in country-level MFAs. The following is an example from South Africa.[8] In 2017, the South African economy processed 746 million tonnes (MT) of materials for the local economy (i.e., not including the materials that left the country as exports or as bunker fuels in ships). Of this amount:

- 112 MT net were added to the country's economy's long-term stocks, or 15% of the total amounts processed.
- 310 MT (41.6%) became solid and liquid outputs.
- 180 MT (24.1%) were emitted as pollutants into the environment. To this can be added 66 MT (8.8%) of water vapour. The great majority of both these releases were generated by the country's energy use.
- 59 MT (7.9%) were released into the environment as dissipative uses (e.g., mineral fertilizers).

Processing operations involved the use of 3 MT (0.4%) of reused materials and 11 MT (1.5%) of recycled materials. This means that 98.1% of the materials processed in the South African economy were extracted as virgin raw materials from the environment.[9]

Possible policy solutions: In their collection of data on solid waste, governments could (a) consider ensuring that comprehensive data on waste generation, including composition, are gathered, which is not limited solely to waste collection data, and (b) extend their data collection efforts to cover all types of solid waste generated in the country, including industrial, construction and hazardous waste, not limited solely to municipal solid waste.

Possible policy solutions: To better quantify waste and pollution as indicators of the level of circularity of their economies, governments could consider developing and regularly updating national MFAs, using these in conjunction with the relevant metrics or indices to track the degree of their economies' circularity. Governments can be supported in these efforts by various tools.[10]

With respect to the triple planetary crises of climate change, biodiversity loss, and pollution:

- At the global level, solid waste is now having a significant impact on climate change. The mismanagement of solid waste, in particular of organic waste (food system waste and other organic waste), has become a major source of human-driven emissions of the potent greenhouse gas methane, being responsible for about 20% of these emissions. The problem is growing: methane emissions from solid waste are expected to increase by 13 MT a year for the next decade alone.[11]
- As for biodiversity, the loss and wastage of food in particular is having a strong but indirect impact on biodiversity. It has been estimated that 14% of food produced is lost from the post-harvest stage up to, but excluding, the retail stage (accurate estimates of food waste generated by retailers and consumers are being prepared).[12] Given that agriculture is

responsible for 66% of threats to species,[13] the agricultural production related to that lost or wasted food is having a significant impact on biodiversity.

- The pollution of the environment by solid waste which has leaked into the environment due to mismanagement is also having serious impacts. Plastic waste and its pollution of seas and oceans is of particular concern. The amounts of plastics in the seas and oceans are already around 75-199 MT. In the absence of necessary interventions, the amount of plastic waste leaking into aquatic ecosystems could nearly triple by 2040. This plastic pollution causes lethal and sub-lethal effects in numerous species of vertebrates and invertebrates. Micro- and nanoplastics can also alter global carbon cycling through their effect (in the form of impacts on metabolic rates, reproductive success, and survival) on primary production in marine, freshwater and terrestrial systems. The release of chemicals associated with plastics through leaching into the marine environment could be having impacts on human health and the health of marine species.[13] The mismanagement of solid waste, especially hazardous waste, is also having strong negative effects on soil, freshwater and marine water quality.[14] This in turn is having strong impacts on biodiversity.

3. Drivers of Waste Generation

As exemplified in the MFAs, in our current highly linear economies the amounts of waste and pollution generated (as well as the amounts of virgin raw materials extracted) are closely linked to the amounts of products we consume. Thus, the drivers of consumption and waste and pollution generation (and virgin raw material extraction) are similar. They have been summarized as follows[15]:

- A growing population, increasing the demand for basic goods;
- As our economies become more affluent, an increasing number of middle-class consumers with larger disposable incomes, purchasing more products per capita (this has been worsened by a trend towards disposable consumerism);
- In addition, the switch by these consumers to products with higher material intensity: more complex products and more highly packaged products.

In the period 1970-2000, at the global level the driver of growing population was somewhat more important than the driver of growing affluence, while the reverse was true in the period 2000-2016. There were marked regional differences: during the latter period, for instance, the driver of affluence was much stronger in the Asia-Pacific and Eastern Europe, Caucasus and Central Asian (EECCA) regions, reflecting the strong economic development of these regions, while the driver of population was stronger in the African and West Asian regions, reflecting their strong population growths.[16]

4. Sources of Solid Waste

There are three fundamentally different sources of solid waste.

1) Solid waste is generated as a result of inefficiencies: in the operations to extract raw materials, whether from the natural environment (virgin raw materials) or from recyclate through recycling (secondary raw materials); in the operations processing those materials into products; in the distribution and use of those products. These kinds of solid wastes can be avoided through the circular economy practices of developing and adopting more efficient technologies, techniques, and practices.
2) Some types of solid waste are generated unavoidably because of the nature of the raw materials which are being extracted and processed. For example, the processing of agricultural produce often extracts a desired product – a fruit, a vegetable – and leaves

behind agricultural residues made up of the rest of the plant (leaves, stalks, roots). These kinds of solid wastes can be minimised through the circular economy practice of design for circularity, finding a new use for these hitherto unused materials and so turning them into new products (in the case of agricultural residues, for example, this could be biofuels, or biochemicals, or biocomposites).

3) Solid waste is generated because products come to the end of their useful lives and are discarded. Although it is inevitable that products will eventually be discarded or anyway be downgraded, many circular economy practices can be adopted to minimise this process, by ensuring that as few products as possible are used in our economies, that the products which are used have as long a useful life as possible in our economies and their use is intensified and optimized (e.g., through sharing solutions), and that at the end of products' useful lives the materials making them up do not become waste because they are recycled and reused to make new products, or, in the case of biological waste the nutrients and carbon they contain are reintegrated into nutrient and carbon cycles.

While the first two sources dominate in the extraction and processing phases of products' lifecycles and the third dominates in the use phase of those lifecycles, they can be present to varying degrees in all the lifecycle phases. For instance, while enterprises will focus on making their products more efficiently, they also use many goods in their production processes which eventually come to the end of their useful lives (e.g., spent cleaning solvent). Also, while households can do many things to extend the useful lives of their products, they can also use them more efficiently, reducing the amount of energy, water, and other materials these products require, and make conscious choices in the selection of these products.

5. Circular Economy and the Waste Management Hierarchy

The waste management hierarchy is a fundamental principle in waste legislation. Legislators state that, in actions taken to deal with solid waste:

- The highest priority should be given to preventing waste from being generated in the first place;
- If this is not possible, the amount of waste generated should be reduced to the greatest extent feasible;
- Any remaining waste should be reused directly, with little or no pre-processing;
- If this is not feasible, the waste should be recycled, where usable materials are extracted from waste through processing and then reused;
- If this is not possible, priority should be given to recovering and using the energy content of the waste, if it has any;
- If not, the waste should be incinerated or otherwise treated to reduce its volume and/or environmental impacts as much as possible;
- Finally, when all other options have been exhausted, any remaining waste should be safely and securely landfilled.[17]

Circular economy practices should play a crucial role in promoting the higher, preferred levels in the waste management hierarchy over the lower levels of energy recovery, incineration, and landfilling. The relevant circular economy practices which do this are described below, following a lifecycle approach. Specific examples are given, to enhance the understanding of the described circular economy practices. Suggestions are made regarding the policy instruments which governments could adopt to promote the practices.

Note that in the implementation of this hierarchy, steps should always be taken to ensure that any environmental impacts which arise during processing, incineration or landfilling are avoided as much as possible.

A. Extraction, Processing, Manufacture, Distribution

Resource Efficient and Cleaner Production (RECP) is an important circular economy practice in the earlier phases of the lifecycle to prevent, or at least reduce, the solid wastes (as well as pollution) which are generated during the extraction of raw materials (agriculture, forestry, fishing and aquaculture; mining), during their processing into finished products, and during the distribution of these products to consumers. Enterprises can use readily available RECP tools and methodologies to identify where and why they are generating solid wastes (and pollution), and what technically, environmentally, and economically feasible options are available to them to reduce, if not eliminate, these wastes, turn whatever wastes remain into by-products, or recycle them.[18] RECP can be targeted at all three of the sources of waste described in section 4 when they are present in an enterprise.

Use of RECP in the food and beverage sector: A company in the MENA region makes sandwich biscuits as one of several types of sweet baked goods. In the cream filling step, the filling tube tended to block. This was leading to 286 tonnes of rejects a year; a good portion of these were recycled, but there was an upper limit on the amounts of rejects that could be recycled, and that limit was being reached. After undertaking a RECP assessment, it was concluded that the root cause of the problem was variations in the viscosity of the cream at the filling point due to the cream's temperature not being properly controlled. The enterprise identified as an option to install a double-walled filling tube, with water at a set temperature running in the outer tube, thus maintaining the cream at a constant temperature and viscosity. It was estimated that adoption of this option would result in savings of a little over €63,000/yr. The investment costs for the new tube were €4,500.[19]

Use of RECP in the wood processing sector: Through a Cleaner Production Agreement reached between the Ecuadorian government and the country's Association of Wood Industries, four wood processing companies undertook RECP Assessments and implemented identified options. The overall results achieved were annual reductions of 322 MWh in electricity consumption, 157,608 gals in diesel consumption, and 29,356 tons in generation of biomass waste. These savings translated into 53,135 tons of CO_{2eq} emissions avoided annually, while the economic savings were US$ 593,101/yr.[20]

The ability of the RECP methodology to successfully help enterprises simultaneously reduce their environmental (and social) impacts as well as their costs has been demonstrated the world over, for enterprises large and small, and in many sectors.[21] However, there are still large numbers of enterprises which either are not familiar with RECP or are reluctant to use the methodology for a variety of reasons.

Possible policy solutions: Governments could consider enacting policies to encourage and support their enterprises, especially Micro, Small and Medium-sized Enterprises (MSMEs), to use the RECP methodology.

- Experience has shown that the most effective policy instruments to promote RECP are those which make information, awareness-raising, training, and skills-creation available to enterprises. Governments can make these inputs available for free or at a subsidised cost.

They can establish free-standing entities to provide the service or add RECP as one further service which existing, relevant service providers can offer (e.g., productivity councils).

- A common barrier to companies adopting resource efficiency and cleaner production is the difficulty for them to access the necessary capital. This is especially true for MSMEs. Policy instruments which help enterprises raise the necessary capital to invest in research and development activities and cleaner and greener technologies (e.g., low-interest lines of credit, loan guarantee schemes) are valuable.
- In some cases, having an efficiency-related certification can help enterprises access new markets or new customers. Government can help by creating such certification schemes (or backing their creation).

While the RECP methodology is primarily used by individual enterprises, an extension of its principles to involve whole value chains has been successfully trialled.[22] Another extension of RECP is industrial symbiosis. This is where the wastes of one enterprise are reused – with little or no prior processing – as raw material inputs by another enterprise,[23] thus reducing the amounts of waste which require further management. Municipalities can also take part in symbiotic relationships with their municipal wastes. Governments can encourage the creation of symbiotic relationships by, e.g., creating – or supporting the creation of – platforms where enterprises or municipalities with wastes can list them and other enterprises can check if there are wastes which they can use as secondary raw materials.

It is important for policymakers to keep in mind that not all RECP options, and more generally not all circular solutions, necessarily reduce overall environmental impacts. Life-cycle assessments (LCAs) can help actors who are considering circular solutions to assess their environmental benefits. Governments can support them in performing LCAs with information, training and consultancy services. Governments, too, should evaluate any planned circular policies for their overall environmental effects.

Resource efficiency can also be practiced by entities in distribution chains bringing manufactured products to the consumers (wholesalers and retailers, as well as transporters). They can work to reduce, if not eliminate, any solid wastes which they generate.

Example in the food and beverage sector: In Mexico City, much perfectly good food is potentially wasted at the retail level as well as during manufacture. However, by partnering with the organisation *Alimento para Todos* (APT; Food for All), retailers as well companies in the food industry have been able to reduce this wastage. They donate food which would otherwise have gone to waste to APT. In turn, through its stores in the city, APT makes a weekly delivery of food packages to over 32 thousand people, thus contributing to a reduction in food insecurity.[24]

Design for Circularity is a key circular economy practice in the earlier phases of the lifecycle. Many of the circular economy practices available in the later phases of the lifecycle and discussed below can only be properly adopted if products are designed to allow for their adoption in the first place. In addition, the ability of manufacturers to use secondary raw materials rather than virgin raw materials – a fundamental requirement to close the final loop in a circular economy – is very much dependent on the design of the product allowing this. Finally, it is design that can turn inevitable wastes into value-added products (guidance for design for circularity is available).[25]

Example in the packaging sector: Rather than using single-use plastic for making its single-use food sachets and wrappings for its products, a new company in Indonesia uses seaweed for making these sachets and wrappings that, at the end, can be dissolved or eaten. The same company has also come up with a material from the South Asia fig tree that holds liquid and can be used for personal care products and applications in medical supplies such as hygienic encasements for medical instruments. It can be composted at the end of its useful life.[26] This is an example of the circular bioeconomy.

Further examples of design for circularity in the built environment are given in the Endnotes.[27,28] Design for Circularity will only work properly if the enterprises integrate their design strategies into circular business models, i.e., business models where enterprises have adopted a circular approach to their products.[29,30]

Examples in the packaging sector: Working with a number of multinational consumer product companies, a Chilean start-up company has built up a system that allows its customers to refill branded household products like washing up liquid, clothes washing liquid, and general cleaning products by using smart powered dispensing machines located in supermarkets along with packaging chipped with RFID which they purchase from the company. Customers credit their account through an app and bring their smart packaging to one of the company's dispensers. The machine will recognise the packaging and dispense the right product at the desired quantity without the need for login or payment. This allows the single-use packaging normally used in these products to be completely eliminated. It also means that the brands can sell their product at considerably lower bulk prices (packaging represents about 30% of the overall price). The company plans to extend its network of dispensers, installing them in convenience stores and service stations.[31]

A number of Indonesian start-ups are offering the same or similar service. One is partnering with the Chilean company to set up the same system in Indonesia. Another start-up, working with brands, provides its customers with returnable and reusable packaging which is suitable for a wide array of products, from household cleaners to personal care items and food products, and which can be used up to 20 times. It has set up a number of community-based points of sale at locations such as waste banks, *warung* stores, and other retail locations, where consumers can purchase the products in the reusable packaging. In the same places, it installs reverse vending machines, which customers can use to return their used packaging and receive cash back for each piece of its packaging they return. The company provides the community the necessary training and support to manage this system. It operates state-of-the-art cleaning facilities to ensure that all returned packaging is thoroughly cleaned and sanitised before it is returned for refilling.[32] A third start-up offers consumers a home delivery solution. Using the company's app, consumers can order the product they need. A specially designed motorcycle will come to the house, and consumers, using their own packaging, can get a refill.[33]

Example in the packaging sector: In Ghana, a number of companies making skincare products with natural raw materials have chosen to offer some of their products in biodegradable containers made from coconut shell rather than in plastic containers. Although these containers are more expensive than plastic containers, leading to an overall increase in the cost of products of 20 to 40%, the companies believe that there is sufficient demand for these completely natural products (packaging included) to make them a viable business proposition.[34] At the end of its life the packaging can be composted.

The (re)design of products and packaging to make them more circular currently requires more effort than designing them for linearity. Enterprises need incentives to make this extra effort. Design for circularity goes beyond (re)designing products. Redesign of current systems should also be considered. This is especially important when promoting Product-as-a-Service options (see below) or ensuring a more efficient (and more equitable) distribution of available products.

Possible policy solutions: Governments could consider using various policy instruments to promote design for circularity.

- One of the potentially more powerful instruments is public procurement.[35,36] Public procurement accounts for 12% on average of GDP in OECD member countries and up to 30% of GDP in many developing countries. By applying a lifecycle approach to the choice of their purchasing criteria, governments can use their public procurement to favour products designed to be efficient during use, to have longer lives (greater durability, more easily repaired, more easily reused) and/or to use recycled or residual materials as raw material inputs, and/or to be remanufactured or cascaded or recycled more easily. Circularity criteria can be part of broader sustainability criteria which the government adopts for its procurement.
- Design for circularity can also be pushed through mandatory targets which products must meet. Such targets have existed for a while for energy efficiency. More recently, targets promoting the uptake of secondary raw materials so as to close cycles have been adopted in the form of a required minimum percentage of recycled material in the make-up of a product. Alternatively, targets have been set on the proportion of products which are to be recyclable, although this does require government to define what constitutes a recyclable product.
- Design for circularity can also be pushed through policy instruments encouraging greater durability by mandating longer warranty periods for certain types of products. Consumer protection legislation often legally requires manufacturers to offer a minimum of three years' warranty on their products; if their product malfunctions during this period, the manufacturers (or retailers) are liable for the costs of repair or replacement. By increasing the warranty period to, for instance, five years, governments can give manufacturers an incentive to make their products more durable.
- Given the strong role of innovation in the circular economy transition, governments can also adapt their existing policy instruments to support innovation specifically aimed at design for circularity (see section 5.D).
- It will be important for developing countries especially to build up the necessary cadre of product designers who are able to apply the principles of design for circularity to the products they design.

Note that other policy instruments which governments can adopt and which are discussed below, while having a different objective, can also lead to a more widespread adoption of design for circularity.

B. Use and Consumption

Consumers can adopt many circular economy practices which can prevent or reduce solid waste, primarily by reducing the number of products circulating in the economy which later are discarded and become waste (type 3 waste in section 4). Less products being made also reduces the volumes of solid waste being generated upstream, during extraction, processing, manufacture and distribution (the so-called "ecological rucksack" of products; types 1 and 2 wastes in section 4); the data cited in section 2 suggest that, on average, this is some 20 times greater by weight than the products themselves.

B.1. At the Point of Sale

Already at the point of sale (POS), before they begin to use products, consumers can make a number of important decisions. They can choose not to purchase, the option which UNEP in its circularity approach calls "Refuse".[37] Such decisions lead to a downward pressure on waste generation since they reduce the number of products in circulation which will later be discarded and can become solid waste. The "Refuse" option can take various forms, the most radical of which is to not purchase new products at all.

Example in the packaging sector: Starting in about 2008, a number of universities, government bodies, townships, and other entities around the world have stopped the sale of bottled water on their premises or within their town precincts, in an effort to reduce the amount of plastic packaging waste which is generated.[38]

Alternatively, consumers can choose to share products through rental schemes rather than purchasing them. This allows individual consumers to receive the service they want from the products while ensuring that fewer of the products overall are in circulation and thus less solid waste is generated later. In the transportation sector, many such rental schemes have existed for a long time (e.g., taxis, buses, trains, airplanes, cars for long-distance journeys), while many new forms of transport-related rental schemes have sprung up with the growth of the internet (e.g., short rentals, city-focused sharing schemes for cars, motorbicycles, bicycles, and scooters). Other, more recent rental-based product-sharing schemes are also appearing on the market. An example of rental in the fashion and textiles sector is given in the Endnotes.[39]

Even when consumers decide that they will purchase products, they can still take decisions at the point of sales which will lead to waste prevention and reduction in the future. They can choose to purchase products which are more durable or which can be more easily maintained and repaired. This means it will take longer for the products to come to the end of their useful lives and become solid waste. An example of giving consumers information with which they can make more informed decisions is given in the Endnotes.[40] They can also choose to purchase products which will be more efficient and generate less solid waste (and less emissions) during use and which are designed for reuse (as in the example of reusable packaging given above) or recycling.

Finally, rather than purchase new products, consumers can choose to purchase products which other consumers have already used and are offering on the resale market, to give these products a new life in the economy ("Reuse" in UNEP's circularity approach[30]). Retailers are becoming increasingly aware of the rising importance of the resale market.

Example of the resale of clothes: "Brick and mortar" second-hand shops selling used clothes have existed for a long time. More recently, various online platforms have sprung up to support consumers who want to sell and buy second-hand clothes. Increasingly, brands are launching their own resale programmes. They are recognising that sustainability for their industry goes far beyond how their products are made; increasing the lifetime of their clothes is especially important. Owning the resale platform allows them to increase the revenue streams from their clothes. It also allows them to ensure that their customers have a very branded experience even during resale. Other perceived advantages: brands can certify the authenticity of their clothes being sold; resale can help them manage difficult-to-predict demand; it also gives them feedback on which of their brands are most popular.[41]

However, for these purchasing options to be practicable, consumers need information at the point of sales to allow them to make reasoned decisions, and they need to be educated to properly understand the information they are being given.

Possible policy solutions: Governments could consider adopting various policy instruments that can support consumers at the point of sale in their decisions about whether or not to purchase more circular products.

- They can undertake campaigns, or finance others to undertake them, to raise the awareness of consumers of the impact which their purchasing decisions can have on circularity.
- They can adopt mandatory labelling requirements. The example of mandating the labelling of certain product types with a reparability index is described in the Endnotes[40]. Mandatory labelling for energy efficiency has been in use for some time, and governments are adopting similar labelling for water efficiency. Other mandatory labels promoting circularity decisions are labels stating the percentage of recycled material in a product. The objective is for consumers to use the information on the labels to choose more circular products to purchase. Note that for labels to work properly, governments need to undertake actions in parallel to educate consumers on the importance of the labels and how to read them. Governments could also consider avoiding – and warning consumers about – the proliferation of unnecessary or misleading labels, which could induce the customer to buy a product whose ecological performance has no solid base.
- They can also support voluntary labelling programmes. An example would be government-designed ecolabelling schemes which enterprises can adopt voluntarily in return for the right to use a special ecolabel. The aim is to signal to consumers products which have better circular or other environmental characteristics than competing products. This approach can be adopted in less mature markets or to stimulate and reward excellency (product performance well above minimum mandatory targets, certification labels for products made from sustainable renewable resources) in more mature markets.
- They can use fiscal incentives to encourage the purchase of circular (but also environmentally-friendly) products, or – the opposite – disincentives to discourage the purchase of non-circular products (an example of the latter which has been adopted in many countries is the requirement that retailers place a charge on plastic bags, to be paid by consumers who choose to take such bags).

Governments could also consider using their public procurement programmes to influence the products offered at the point of sale. Governments could also, for instance, require that products they wish to purchase be used rather than new, so encouraging the second-hand market. To mainstream this approach in procurement programmes, governments could require that a certain fraction of the points used in evaluating any bid have to be devoted to products' circularity properties (or their environmental sustainability properties more generally).

B.2. During Use and Consumption

Once consumers have purchased products, they can adopt circular economy practices during the use and consumption of those products, which will prevent and reduce future waste generation. They can use and consume them more efficiently ("Reduce" in UNEP's circularity approach[30]).

Example of consumers reducing waste in the food sector: Food is often unnecessarily wasted in the kitchen. Often, this is because food has gone beyond its "Best Before" date. A kitchen management app has been developed that helps users buy groceries and plan meals with a precise view of what is needed, putting an end to food waste. In particular, its expiry tracking system is designed to help consumers avoid habits which drive food waste generation, such as confusion over expiry labels, premature binning, overbuying, etc. As of 2018, the app had at least 15,000 users in Asia, Europe and North America.[42,43]

Consumers can also properly maintain their products and repair them – or have them repaired – if they break ("Repair" in UNEP's circularity approach[30]). By doing so, they extend the useful lives of their products, thus reducing the volume of products becoming solid waste. In the case of repair, a major barrier is its cost compared to the cost of purchasing new products. One important factor in the cost equation is the ease of reparability, which is a product design issue as well as a business strategy issue (see section 5.A). An example from the electronics sector of ease of repairability as one element of a company's circular business plan is included in the Endnotes.[44]

Consumers can also choose to have their products reused by other consumers once they have finished using them (the "flip side of the coin" of the circular economy practice already discussed in section 5.B.1). Ensuring a string of multiple users for the same product extends products' useful lives, thus reducing the volume of products eventually being discarded and becoming solid waste.[45] An example from the packaging sector of a company offering this circular practice as a circular business plan is given in the Endnotes.[46] In this case, too, there are barriers to consumers purchasing circular good. They are often not aware of the fact that the way they use and consume products can support circularity. In addition, the price signals perceived by consumers often work against them adopting circular practices.

Possible policy solutions: Governments could consider adopting policies aimed at overcoming both these types of barriers.

- They can undertake campaigns, or finance others to undertake them, to raise the awareness of consumers in how to use and consume products more efficiently, reducing wastage.
- With respect to repair in particular, where consumers often consider repair too expensive, governments can undertake several actions to reduce repair costs. For instance, they can work directly on repair costs by reducing, or even eliminating, VAT or sales tax on repairs, or allow consumers to deduct repair costs from their taxable income. Other policies make repair less difficult and therefore less costly. For instance, governments can require manufacturers to keep spare parts available for a minimum period of time and to make repair manuals available to third-party repairers for certain product types. Also, governments can use their TVETs, or support private training institutions, to ensure a sufficient supply of properly trained repairers.
- Governments can also use fiscal instruments to encourage product reuse, e.g., reduce VAT or sales tax on the sale of second-hand products.

C. Remanufacturing and Refurbishing, Cascading, Recycling

As noted above, most of the circular economy practices described in the previous section lead to waste prevention or reduction, by reducing the number of products circulating in the economy which consumers eventually discard. But even when products do come to the end of their useful lives, other circular economy practices can be adopted to extend the useful lives of (a) the **parts** which make up a product (through remanufacturing or refurbishing) or (b) the **materials** making up the products (through cascading or recycling).

C.1. Remanufacturing/Refurbishing and Cascading

In remanufacturing, products which are entirely or partially comprised of parts are disassembled, any worn or broken parts are removed, all remaining parts are cleaned, removed parts are replaced by reused or new parts, any software is upgraded, the products are reassembled, and then inspected and tested to ensure they have been restored to original working condition or better. The remanufacturer issues a warranty reflecting this status[47] ("Remanufacture" in UNEP's circularity approach[30]). Refurbishing is similar but leads to a product which is of a lower quality, and the warranty – if there is one – will reflect this. By extending the useful lives of product **parts**, remanufacturing and refurbishing prevents and reduces waste generation, by reducing the volume of parts that are discarded. Often, programmes in this space will integrate remanufacturing / refurbishing activities with their reuse and recycling activities into one circular business model.

Example from the Electrical and Electronic Equipment sector: An Egyptian company collects discarded IT equipment from companies, organizations, workshops, and individuals. A series of collection centers have been established in each of the country's districts, creating more than 1,000 jobs. Individual collectors can also bring in e-waste, being paid US$100 for every 13-15 kg of discarded IT equipment they bring. The discarded equipment is sorted in the company's warehouse, where the reusable equipment is separated from the rest. Reusable equipment is refurbished and sold in the local market (if a refurbished piece of equipment is sold within 10 days after pick up, the entity handing it in gets paid). All other equipment is dismantled manually. The recyclable material is transported to plants for shredding, smelting and refining. The smelting / refining processes are done by partners in Europe and Asia. In all cases, the company offers 100% safe data destruction.[48]

In products where there are no parts, such as textiles, it is the useful life of the materials making up them up which can be extended, through the practice of cascading. Cascading differs from recycling in that the materials are reused with little or no prior processing to make new products. Note that these products are often of a lower value than the original products. An example of an NGO undertaking cascading in the textiles sector is given in the Endnotes.[49,50]

Possible policy solutions:

- Governments could consider setting sectoral targets on the percentages of products (or components) brought to market which are remanufactured or made from cascaded materials, for the appropriate products.
- Governments could consider developing a certified "remanufacturing mark", or support the development of such a certification, to build confidence among consumers in remanufactured products or components.

C.2 Recycling

Finally, once products, or their parts, or their materials, can no longer have their lives extended with little further processing, it is time for the materials (or in the case of biological materials, the nutrients or chemicals) making up those products to be extracted through the practice of recycling, so that they can be cycled back into new products. Recycling differs from the previous practices of remanufacturing, refurbishing, and cascading in requiring considerable processing to extract the materials (or nutrients or chemicals) from the solid waste.

The ideal would be for recyclers to receive very pure streams of waste products, which would allow them to produce a recovered material of good enough quality to be reused to make the same, or similar, products. (so-called closed loop recycling). The result of closed-loop recycling is materials which can be used many, many times over before becoming solid waste. Examples of solid waste streams which closely approximate closed loop recycling are PET bottle-to-PET bottle recycling and aluminium cans-to-aluminium cans recycling. An example of PET bottle-to-PET bottle recycling is given in the Endnotes.[51]

For circular economies, the goal should be to have all recycling operations be closed loop recycling. However, many waste streams, especially those from municipal waste collection programmes, are a mix of discarded products made with different materials. The more discarded materials made with different materials are mixed together, the more difficult – and therefore expensive – is their processing to recover secondary raw materials, and the lower tends to be the quality of the recovered material. This means that the recovered material can often only be used to make lower quality products, and the materials can only go through recycling loops a few times before becoming solid waste (so-called open loop recycling).

The key, then, to high-quality recycling is separation. Many technologies have been created to sort mixed waste streams and more are being developed, but these add to the expense of recycling. However, separating discarded items at source, i.e., by households, can considerably reduce downstream sorting costs. Most developed countries now require sorting at source, with developing countries moving in this direction, although in the absence of government regulations requiring separation at source they are looking to encourage voluntary separation at source.

Examples of sorting programmes: In 1991, the municipal government of the city of Curitiba, in Brazil, created a programme called “Cambio Verde” (Green Exchange), where citizens are encouraged to bring their segregated organic and non-organic recyclable wastes to over 100 waste stations. For every 4 kg of recyclable waste collected, residents are rewarded with 1 kg of fresh fruits, vegetables, or eggs, or with bus tickets (the municipality buys excess foodstuff that would otherwise go to waste). Participation among Curitiba households is high, reaching about 70%.[52,53]

A start-up in Lagos, Nigeria, is a pioneer in door-to-door collection of recyclables. It has over 17,000 subscribers. Their collectors initially used a fleet of relatively cheap, and locally assembled, cargo bikes called “wecycles”. Now, collection has incorporated motorized tricycles, vans, and trucks to expand the company’s reach across the metropolitan area. Subscribers who give materials to the company are rewarded with points per kg of recyclables, which they can exchange for essential goods such as food and household items.[54]

Many examples of open loop recycling exist. Two are given here, one for products made of biological materials and one for products made from mineral materials.

Example from the agricultural sector: What is probably China’s largest dry anaerobic digestion facility has recently come on line near Shanghai. The plant processes some 19,000 T/yr wheat straw and 46,000 T/yr pig manure. The biogas which is generated is used to generate the electricity and supply the heat which the plant uses. The digestate is further composted, with the resulting compost being used in agriculture.[55]

Example from the built environment: Concrete from demolished buildings can be hard to recycle, but it can be done. Recycled concrete aggregate is one such way. Concrete from demolished buildings and infrastructure is first checked that it does not contain materials such as wood or metal that could affect the final product's strength. Then it is crushed and mixed with an aggregate such as sand. When used to produce new concrete construction, concrete quality can be maintained by optimising the mix design (typically, recycled aggregate is restricted to 20% of the aggregates). Recycling concrete contributes to the conservation of mineral resources and reduction of land use. However, recycling concrete may also require slightly higher cement contents when recycled aggregates are used, leading to higher greenhouse gas emissions. This effect can be countered by the carbonation of recycled concrete. Much higher emission reductions can be achieved by reducing the use of emission intensive cement clinker, via, e.g. the use of Limestone Calcined Clay Cement (LC3). Also, asphalt can be recycled, achieving large environmental benefits.[56,57,58]

Possible policy solutions:

- Governments could consider adopting Extended Producer Responsibility (EPR) regulations,[59,60,61] with a modulated fee scheme. The original objective of EPR regulations is to implement the Polluter Pays Principle, by shifting the cost of managing specific categories of discarded products away from municipalities, and ultimately the taxpayers, onto the manufacturers of those products, and ultimately the consumers of those products, through increases in sales prices to cover the costs of operating EPR schemes. Depending on how EPR regulations are designed, recycling can be promoted by leading to a better aggregation of similar recyclable materials and thus reducing sorting costs and making recycling more competitive than other forms of waste management. However, in their original form EPR regulations only weakly promote other, upstream circular practices, because the fees which enterprises pay to cover the costs of EPR schemes do not distinguish between more and less circular products (e.g., between products which are difficult to repair and those which are easy to repair). Recognizing this, recently there have been moves to modulate EPR fees to take into account products' degree of circularity: the more circular the product, the less fee the manufacturer (or importer) pays. This can give enterprises greater incentives to adopt design for circularity.[62] Since the difference in fees can be reflected in sales price differences at the point of sale, this can also encourage consumers to purchase more circular products. There is evidence that modulation is having some effect in further encouraging recycling over other waste management operations, but fee structures do not yet focus much on bringing about change in the earlier phases of products' lifecycles.[63]

D. The Role of Innovation in Promoting the Adoption of Circular Practices

All of the case studies described above have required innovation: in the form of product (re)design,[22] creation of new business models,[25,64] or development of new partnerships with other actors in the economy.[65,66] Innovation will be at the heart of all new circularizing practices, and government policies need to be crafted to support these efforts.[67] In many cases, it is a question of governments adapting existing policies which promote innovation to specifically promote circular innovation.

On the supply side:

- Governments often already have programmes which support incubation of start-ups. These programmes can be adapted to focus on supporting new businesses which are developing circular alternatives – either circular products or circular business models – to existing linear

products or business models. If governments do not support incubation programmes, they can consider creating new incubation programmes for this purpose. To ensure that innovations which successfully graduate out of incubation programmes get the continued support they need to scale up, governments could consider engaging with the finance sector to encourage them to support accelerator programmes which can bring successful incubatees to the next level and allow them to network with potential investors.

- Governments can also adapt their existing R&D programmes to make co-funding available for businesses or individuals searching for alternative circular materials or new circular product design solutions.
- Governments can also help businesses cross the so-called “valley of death” between the R&D and start-up phase and full-scale operation, by offering them access to government-funded demonstration programmes and low-interest loans or loan guarantee schemes.
- Where governments have National Innovation Strategies, they could consider adapting these strategies to ensure that they cover the search for circular solutions.
- Governments can use their convening power to create alliances between the relevant stakeholders: between business and academia to create R&D alliances; between businesses to create industrial symbiosis clusters or to create product reuse clusters.
- Many of the policies described earlier can also be push factors for innovation, e.g.: eco-design standards such as minimum recycled content; required labelling on, e.g., repairability; strengthened EPR schemes with modulated fee schemes; increasing minimum product warranty periods; etc.

On the demand side:

- Governments can use their public procurement programmes to encourage circular products, setting as criteria to be met one or more of the circular practices discussed above.
- Governments also need to support the development of the necessary standards (along with the requisite certification systems) to build the market’s trust in the efficacy and viability of circular alternative materials and products.
- Governments can also use fiscal incentives (e.g., removing subsidies on the virgin raw materials, taxing these same materials, reducing the tax burden on alternative materials and products) to reduce the cost of the circular alternatives.

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