The Circular Economy and Climate Mitigation

A STAP Advisory Document
May 2021

STAP SCIENTIFIC AND TECHNICAL ADVISORY PANEL
An independent group of scientists that advises the Global Environment Facility

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The Scientific and Technical Advisory Panel (STAP) provides independent scientific and technical advice to the GEF on its strategies, programs and projects. https://stapgef.org

ABOUT GEF:
The Global Environment Facility (GEF) was established on the eve of the 1992 Rio Earth Summit to help tackle our planet's most pressing environmental problems. Since then, the GEF has provided more than $21.5 billion in grants and mobilized an additional $117 billion in co-financing for more than 5,000 projects and programs in 184 countries. Through its Small Grants Programme, the GEF has provided support to more than 25,000 civil society and community initiatives in 135 countries. https://www.thegef.org

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EXECUTIVE SUMMARY

The circular economy offers an alternative approach to the current linear economic model. Rather than extracting raw materials to make, use and eventually dispose of products and goods, circular economy approaches focus on maintaining resources in use for as long as possible, extracting the maximum value while in use, and recovering and recycling products and usable materials at the end of their serviceable life.[1]

Recent Scientific and Technical Advisory Panel (STAP) reports have highlighted the role that circular economy interventions can play in addressing global environmental challenges, such as in food systems, plastics pollution, and chemicals and waste management. STAP has also evaluated how circular solutions can deliver global environmental benefits while advancing local socioeconomic benefits, such as jobs, health and clean air and water.

This report examines how the circular economy can support more ambitious nationally determined contributions to achieve the goals of the United Nations Framework Convention on Climate Change and deliver other environmental and socioeconomic benefits.

The report presents 14 circular climate change interventions (Annex 1) in sectors of interest to the Global Environment Facility (GEF), including agriculture and food, plastics, and infrastructure, with case studies illustrating successful implementation.

This report builds on previous STAP advice on implementing circular economy approaches in plastics and food systems,[2] as well as a commissioned technical background paper.[3]

The report makes the following **recommendations**:

1. **Design projects in accordance with STAP's foundational enabling conditions**, which are of broad applicability, including to circular economy projects. These conditions include systems thinking; a robust theory of change; innovation and scaling; appropriate multi-stakeholder dialogue; monitoring, evaluation and learning; consideration of behavioural change; and durability.

2. **Consider how circular economy approaches could be applied in GEF-8 programming more broadly, especially in the next generation of integrated programming.**

3. **Promote measures to improve access to finance and to assistance with business planning.**

4. **Facilitate South-South knowledge and technology exchange for circular solutions.**

5. **Develop policies and institutional frameworks that are conducive to circular economy approaches.**

6. **Develop the GEF's knowledge management system to include what works, what doesn't, why and how, and in what contexts, for circular economy approaches.**

7. **Work in partnership with others to facilitate innovation, attract finance and promote more widespread adoption and replication of circular economy solutions.**

1.0. THE CIRCULAR ECONOMY AND CLIMATE CHANGE MITIGATION

Climate change is an existential threat to humanity, but progress in reducing greenhouse gas emissions is slow, and to limit warming to 1.5°C, global emissions would need to be reduced by 50% in the coming decade and reach net zero levels by 2050.[4]

Current mitigation efforts are often relatively narrow in scope and often focus on specific sectors or activities, such as increasing renewable energy, improving energy efficiency or avoiding methane and land use-related emissions, rather than on comprehensive decarbonization pathways.[5]

The circular economy approach provides an opportunity to reduce greenhouse gas emissions and transform how materials are extracted, processed, designed, used and returned to production systems at end-of-life. This approach is an alternative to the current linear economic system of make, use and dispose. It keeps resources in use for as long as possible, extracting the maximum value in use, and recovering and recycling products and usable materials at the end of their serviceable life.[6] Extracting, processing, handling and eventually disposing of materials, food and energy is estimated to cause 70% of global greenhouse gas emissions and more than 90% of biodiversity loss and water stress.[7]

The circular economy approach can help countries develop more ambitious emission reduction targets,[8] meet their nationally determined contributions,[9] contribute to a low-carbon future and leapfrog linear economic development models that have contributed to environmental degradation.[10]

This report reviews 14 circular economy interventions in sectors of interest to the Global Environment Facility (GEF) (Annex 1), with case studies of successful implementation that illustrate the effectiveness of the circular economy in delivering climate change mitigation and other environmental objectives – for example, clean water and healthy soils, forests and marine ecosystems – as well as socioeconomic co-benefits.

The report builds on previous Scientific and Technical Advisory Panel (STAP) advice on implementing circular economy approaches in plastics and food systems,[11] where the GEF is already financing a number of investments,[12] and a commissioned background paper.[13]

The interventions are grouped into two categories, depending on whether the approach is primarily biological or technological in nature (Figure 1). The biological cycle, on the left side of the diagram, involves renewable and biodegradable materials that do not cause harm to human health or the environment during or after their use (see also Box 1). The materials used can be returned to the environment through processes such as composting or anaerobic digestion. Examples include feeds, food, plants, wood and inorganic matter that are cycled through natural systems.

The technological cycle, on the right side of the diagram, involves manufactured, finite and durable materials that may be harmful to the environment but that can be used, reused, maintained, reprocessed or returned to use via a closed-loop system (see Box 2). They include inorganic materials such as plastics, concrete, metals and synthetic chemicals, as well as biological materials, such as wood, cotton and bioplastics, that have been modified for use in technological cycles.[14]

Circular economy initiatives mimic natural ecological systems, which are by definition regenerative and resource efficient, in the extraction, processing, handling and use of materials. Successful circular economy initiatives are systems based[15] and recognize the importance of coordination at all levels with businesses (small, medium and large), consumers and governments.[16]

The key elements of a circular economy model include:[17]

- **Prioritizing regenerative resources:** Ensure that renewable, reusable and non-toxic

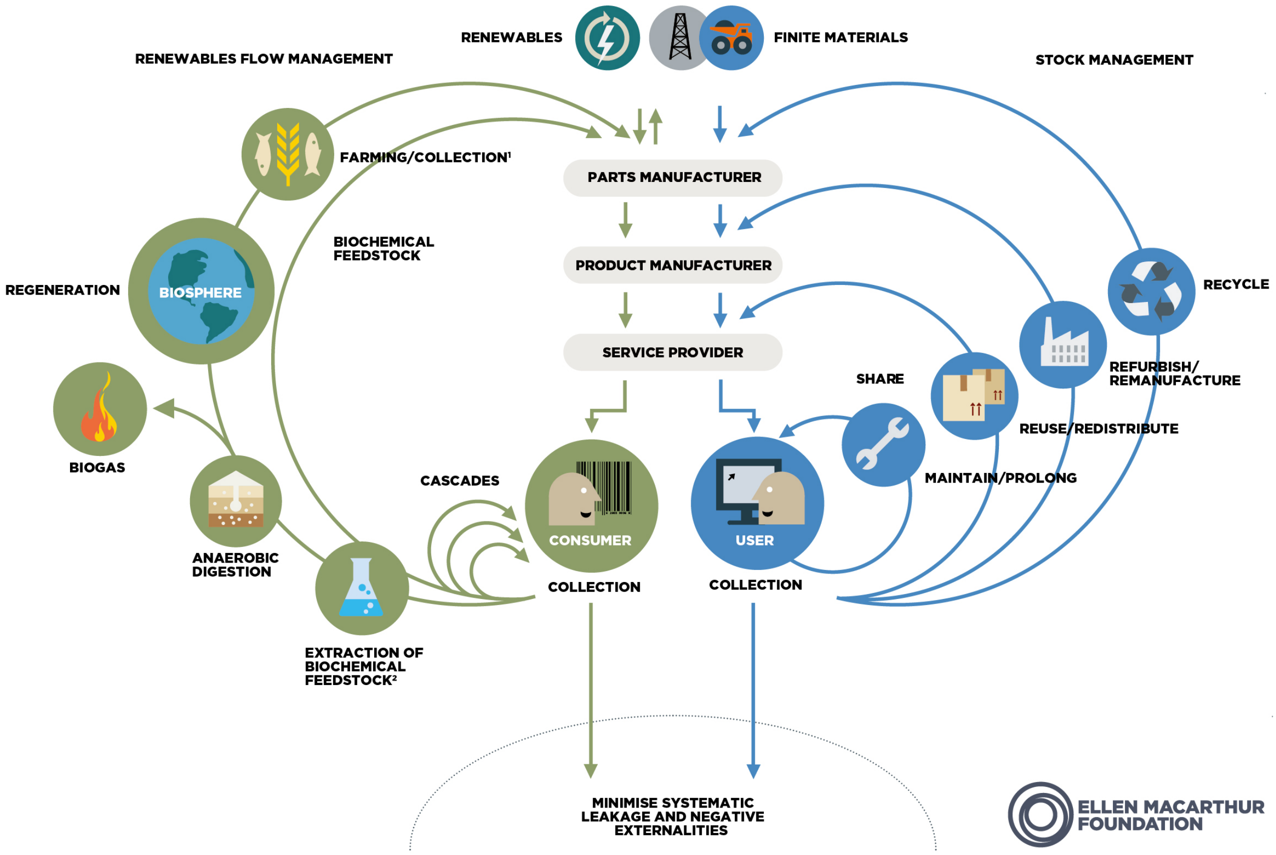


Figure 1: The circular economy with the biological cycle (left) and technological cycle (right).

resources are efficiently used as materials and energy.

- **Designing for the future:** Adopt a systemic, full life cycle perspective during design that promotes the use of the right materials; design products for an appropriate lifetime and for extended future use, reuse and recycling.

- **Stretching the lifetime of products:** Maintain, repair and upgrade resources while in use to maximize their lifetime and give them a second life through appropriate strategies, where applicable.

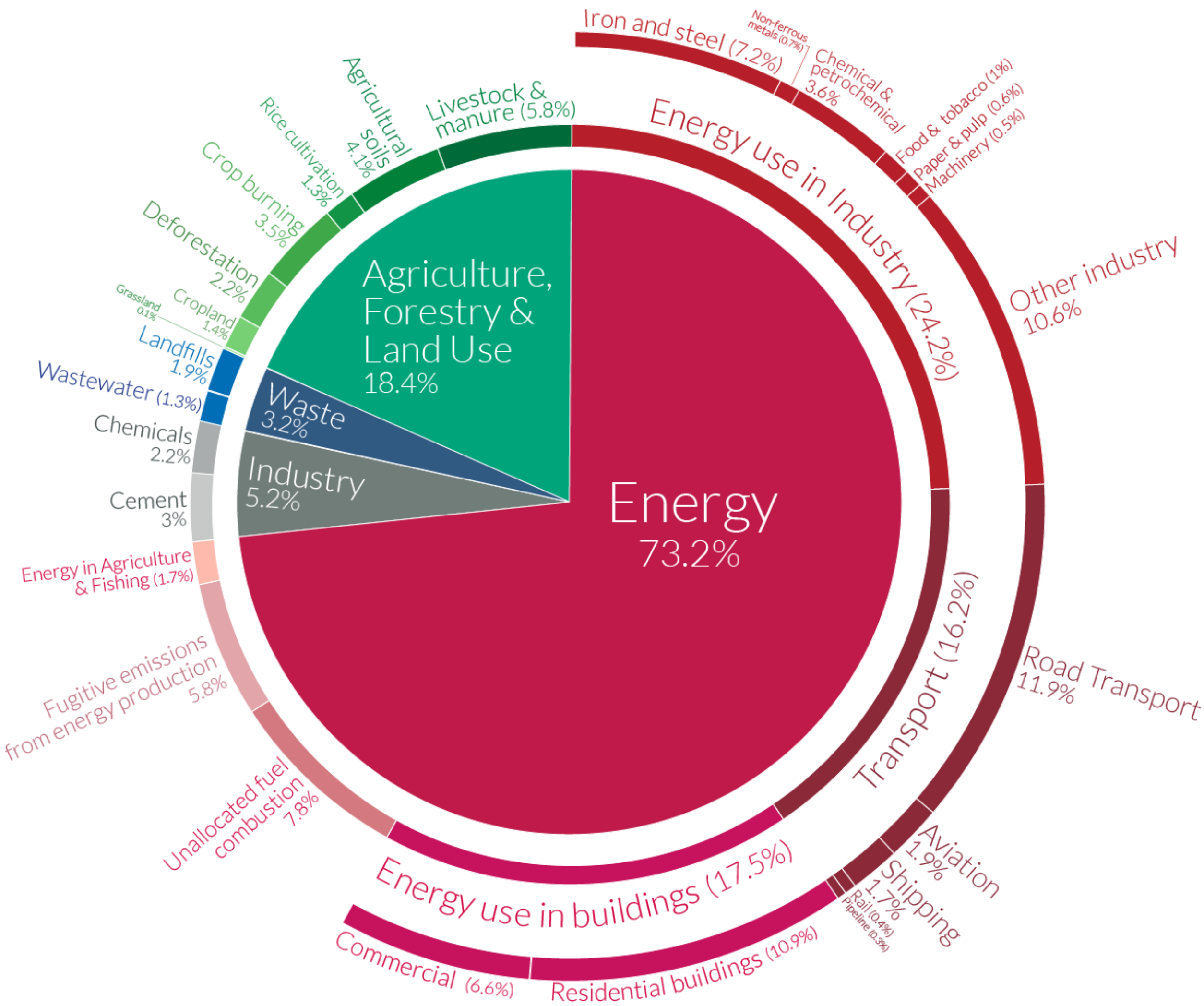
- **Using waste as a resource:** Use waste streams as a secondary resource and recover waste for reuse and recycling.

- **Rethinking business models:** Consider opportunities to create greater value and align incentives through business models that build on the relationship between products and the services they provide, and thereby promote efficient resource use.

- **Teaming up to create value:** Work together throughout product value chains to increase transparency and create shared value.

- **Incorporating digital technology:** Track and optimize resource use and strengthen connections between supply chain actors through digital and online platforms and technologies.

The circular economy approach helps minimize waste disposal and the unsustainable extraction of virgin raw materials. Most current carbon dioxide emission mitigation efforts, including those addressing methane, nitrous oxides, fluorinated hydrocarbons and black carbon, are largely sectoral in nature (Figure 2). By ensuring that materials and resources are used efficiently (i.e. increasing product value retention and lifetime and lowering consumption levels), the circular economy augments sectoral climate change mitigation efforts by reducing greenhouse gas emissions from extraction, processing, manufacture and use throughout supply and value chains.



Global greenhouse gas emissions by sector for the year 2016. Total emissions equals 49.4 billion tonnes CO_2eq.

Source: Ritchie and Roser, 2020. https://ourworldindata.org/emissions-by-sector

2.0. KEY INTERVENTIONS IN THE CIRCULAR ECONOMY

There are significant opportunities for countries to use circular economy approaches to achieve climate, other environmental, sustainable development, and socioeconomic goals.

Annex 1 examines 14 interventions in multiple sectors to show how circular economy approaches can be incorporated into GEF investments (see Boxes 1 and 2). Each intervention highlights key elements of the circular economy model and its climate, environmental and socioeconomic benefits. Each also includes a case study illustrating successful examples.

3.0. RECOMMENDATIONS

Much of STAP's recent work has been about how to improve the design of projects, in particular by paying attention to several **foundational enabling conditions**,[18] which are equally applicable to circular economy projects. These foundational enabling conditions are detailed in Box 3.

GEF-8 PROGRAMMING

The proposed GEF-8 programming directions for the next phase of the GEF (2022–2026) build on progress with large-scale integrated programming to address the major drivers of environmental degradation and to deliver multiple global environmental benefits in climate change, biodiversity, chemicals and land degradation. The evidence suggests that integrated programming delivers greater impact per unit of investment and creates the conditions for transformational change. Under GEF-7 (2018–2022), there were three Impact Programs: Sustainable Cities, expanding global city coverage and innovations; Food Systems, Land Use, and Restoration, covering all major commodities and important staples; and Sustainable Forest Management, covering the Amazon, the Congo Basin and important dryland landscapes. GEF-8 will continue this approach, with integrated programming to deliver transformation in five key global systems: health, energy, natural resources, urban areas and food.

The GEF should consider how circular economy approaches could be applied in GEF-8 programming, especially in the next generation of integrated programming. There are good opportunities for circular economy solutions in the Sustainable Cities and Food Systems, Land Use, and Restoration Impact Programs, as well as further opportunities in global supply and value chains for major food crops and commodities, fashion and textiles, and electronics.

FINANCE

The GEF, and countries, should promote measures to improve access to finance and to assistance with business planning.

For example:

Case study 2: The Kenya Biogas Programme provides biodigesters to individual households, which can use them to process manure from livestock. The energy generated provides fast and smokeless cooking. Unwanted slurry from the digestion process provides organic fertilizer, thereby reducing the need for synthetic fertilizers. The model includes marketing and business development for the biogas sector.

BOX 1: CIRCULAR ECONOMY INTERVENTIONS WITHIN THE BIOLOGICAL CYCLE

1. Reducing emissions from crop production through regenerative agriculture
   Regenerative agriculture (crop rotation, minimum tillage, green manure, integrated pest management) can reduce greenhouse gases, land degradation and water use, while boosting farmer income and welfare.
2. Improving resource efficiency in livestock production
   Improving resource efficiency in livestock production involves using (i) crop residues as animal feed, (ii) manure management to improve soil fertility and (iii) waste-to-energy processes. These activities reduce emissions and lead to enhanced food security and incomes.
3. Shifting to alternative protein sources and sustainable diets
   Meat consumption could grow 80% by 2050, but a transition to plant-based diets could reduce food-related emissions substantially and contribute to meeting the Paris climate goals, as well as reducing human morbidity and mortality.
4. Reducing food losses from harvest to processing
   Averting food loss at production, storage and processing stages through infrastructure improvements and information technology can significantly reduce emissions and create new employment opportunities.
5. Avoiding food waste at the retailer and consumer levels
   Although most food waste at retail and consumption stages occurs in the richest countries, innovations in infrastructure and information technology, as well as consumer awareness, can significantly reduce food losses in Global Environment Facility recipient countries.
6. Closing the loop on organic waste
   While reducing organic waste at source is most effective in reducing emissions, effective and low-cost approaches exist for managing organic waste streams and wastewater and converting these resources into compost, soil treatments and energy.
7. Deploying bio-based materials and accelerating the bioeconomy
   Bio-based inputs can replace many traditionally used and carbon-intensive materials in construction, clothing production and manufacturing if managed closely with food production; such materials include bioplastics, packaging, plant fibre textiles and bio-cement.

BOX 2: CIRCULAR ECONOMY INTERVENTIONS WITHIN THE TECHNOLOGICAL CYCLE

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8. Making the renewable energy transition circular
   A vast expansion of renewable energy production is needed to ensure net zero emissions by 2050. But to ensure success, most raw materials must derive from recycling and incorporate design for remanufacture.
9. Making the most of widely used materials
   Our world is built on key materials such as cement, steel and aluminium. Much greater efficiencies are possible in the energy required for production and use, and end products can be redesigned for longevity, repurposing, disassembly and recycling.
10. Incorporating circular design in construction
    Alternative forms of materials, particularly concrete, and advances in building design can dramatically reduce the embedded emissions in construction as well as the long-term emissions from buildings' operation.
11. Incorporating the circular economy in electrification of transport
    Electrifying transport is key to reducing emissions in the sector where they are growing the fastest, and circular approaches can ensure that the dramatic increases in battery production required incorporate reuse and remanufacturing principles from the outset.
12. Expanding non-motorized and shared mobility
    Creating space and infrastructure for non-motorized transport (e.g. walking, cycling), emphasizing shared mobility (e.g. public transport) and ensuring transport connectivity are central to promoting zero-emission urban transportation systems.
13. Scaling up climate action across product value chains: textiles and electronics
    Design is key to lowering emissions in textiles and electronics through (i) the use of bio-based fibres in clothing, (ii) recycling and imbedding of remanufacturing principles in electronics, and (iii) improved durability in both sectors.
14. Incorporating eco-innovation in industrial clusters, small businesses and informal networks
    Much success in the circular economy will depend on innovation, through manufacturers and industries collaborating to promote resource-use efficiency and to reduce waste in the manufacturing and use of products.

BOX 3: KEY ENABLING CONDITIONS IN PROJECT DESIGN

STAP's foundational enabling conditions for developing transformative projects and programs.

- **Apply systems thinking**[19] by devising a logical sequence of interventions that is responsive to changing circumstances. Address interconnected environmental, social, economic and governance challenges across sectors in design and implementation, with an eye towards resilience and durable transformational change.
- **Develop a clear rationale and robust theory of change**[20] to tackle the drivers of environmental degradation by assessing assumptions and outlining causal pathways and by devising responses that are robust to future change and adaptive if desired outcomes do not materialize.
- **Choose the innovations**[21] **to be scaled** (including technological, financial, business model, policy and institutional innovation). Allow flexibility in project preparation to accommodate the additional transaction costs and time required to tackle complex issues through multi-agency teams.
- **Assess climate risk**[22] at the project development stage and develop ameliorative actions to ensure that project outcomes are achieved.
- **Maximize global environmental benefits** by improving effective integration and by identifying positive synergies among multiple benefits. Avoid doing harm by minimizing negative interactions and managing any trade-offs, including climate risk and other long-term changes.
- **Identify and enumerate co-benefits**, including environmental benefits beyond the global environmental benefits, for example improvements in air quality and water quality, as well as socioeconomic benefits such as those related to jobs, food security and health.
- **Develop multi-stakeholder dialogue**[23] from inception and design through to project completion, ideally building on existing platforms, and flexibly structure the project design to extend and evolve towards durable transformational change.
- **Analyse the barriers to, and enablers of, scaling and transformation**, for example institutional, governance, cultural and vested interests. Assess the potential risks (including climate risk) and vulnerabilities associated with the system to measure resilience to shocks and changes and the need for incremental adaptation or more fundamental transformational change.
- **Establish a monitoring, evaluation and learning process** to track the intended innovations, integration and transformation, as well as indicators of durability. Develop explicit plans and funding for good-quality knowledge management, including sustainable databases and simple, useful and usable common indicators. These activities are essential for gathering lessons learned, for scaling up and for applying adaptive management.
- **Consider explicitly whether the project requires behavioural change**[24] by applying STAP's six-point checklist and asking related questions.
- **Ensure durability**[25] in project outcomes and impacts by applying all the above key elements and engaging the right stakeholders; building the incentives for these key actors to act; incorporating adequate flexibility into project design and implementation; and underpinning it all with a systems thinking approach.

Case study 4: In Nigeria, ColdHubs provides a pay-as-you-store modular solar-powered walk-in cold room to reduce post-harvest loss of vegetables and fruits, which might otherwise account for up to 50% of annual production.

Case study 7: In the Philippines, Piñatex is a commercially available bio-based alternative to traditional leathers made from waste leaves from pineapple farming. Biogas and organic fertilizers are by-products of the process.

Case study 9: In India, the SWaCH is a member-owned trade union that offers a decentralized door-to-door waste collection and separation service that provides recyclable material for reuse. This integrates informal waste pickers into the economy and generates climate, other environmental and socioeconomic benefits.

Circular economy interventions may incur substantial upfront costs, for example adopting bio-based material in construction, building recycling plants for metals and other inorganic waste, building new infrastructure, retrofitting existing production systems or supply chains, building new distribution and logistical arrangements, and retraining staff.[26]

And circular interventions may have long lead times before they break even and show a return on investment; for example, regenerative agriculture or agroforestry may take five years or more to deliver higher yields and revenues, which might not align with investors' expectations.

The adverse environmental effects of traditional products or processes may not be adequately reflected in investment decisions because they are not monetized,[27] and some benefits of a circular approach may not be easily quantifiable in monetary terms. (Natural capital accounting can provide governments with better information about the value of natural assets.)

Small- and medium-scale enterprises, including in the informal (i.e. unrecorded and unregulated) economy and smallholder farmers, may lack access to adequate finance or may be reluctant to invest because they have limited creditworthiness or collateral.

TECHNOLOGY: CAPACITY, ACCESS, EXCHANGE AND TRANSFER

Not all circular economy solutions can be readily applied everywhere. Technology transfer, including North-South and South-South cooperation, in deploying circular solutions is essential.

GEF-8 should facilitate South-South knowledge and technology exchange for circular solutions, including by building on existing mechanisms, for example the global platforms of the GEF's Sustainable Cities and Food Systems, Land Use, and Restoration Impact Programs.

Some lower-tech circular solutions that can be easily deployed in all countries without a requirement for advanced technologies – for example, agroecology, non-motorized transport and composting in food systems – could be deployed rapidly.

INSTITUTIONAL, REGULATORY AND POLICY ALIGNMENT AND COHERENCE

The GEF, and countries, should develop policies and institutional frameworks that are conducive to circular economy approaches, including embedding national circular economy plans in national development strategies and ensuring that these plans are aligned with socioeconomic priorities, such as job creation, economic diversification, food and energy security, air quality and health improvement, and poverty reduction.

Regulatory and policy frameworks should avoid inadvertently supporting the continued extraction of virgin raw resources. For example, environmental legislation focused on minimizing end-of-pipe pollution, rather than incentivizing upfront product design or extended product life cycle, could slow progress towards circular economy approaches.[28]

Circular solutions address material resource consumption by examining the links between economy, society and environment – a whole-of-society approach. However, governments, businesses and funding agencies often focus on siloed sectors and may not be geared towards a systems thinking approach. For example, circular interventions in the food sector need to consider the interactions between food, environment (air, land, water and biodiversity), human health and the economic well-being of consumers and agricultural stakeholders.

And institutional frameworks often do not incorporate the informal sector,[29] where many successful circular approaches have evolved naturally, for example among smallholder farmers, waste collectors and recyclers, as well as repair and remanufacturing services.

Informed legislation and regulation can help promote circular economy approaches, for example through (i) product take-back schemes under which producers are responsible for material flows back into new products, (ii) products-as-a-service, (iii) product maintenance and repair, (iv) extended producer responsibility, and (v) product stewardship.

The net effect of a circular economy on livelihoods is generally estimated to be positive;[30] however, it may result in fewer jobs in some sectors, for example in the extraction and processing of raw materials, often in low- and middle-income countries.[31] Automation and restructuring may also lead to job losses[32] and to a reluctance to adopt circular measures. Policies and solutions for transition may need to be incorporated into circular economy strategies,[33] for example alternative livelihoods, social protection, capacity-building and retraining.[34]

KNOWLEDGE MANAGEMENT

The GEF should develop its knowledge management system to include what works, what doesn't, why and how, and in what contexts, for circular economy approaches.

The GEF is developing a new knowledge management system for GEF-8. STAP's GEF-8 paper[35] recommended that the GEF should, "codify monitoring, evaluation, and learning…[to] develop a knowledge management system that documents best practices, what works, what doesn't, and why".

This approach would be very helpful in providing a basis for wider adoption of circular solutions, creating circularity targets for businesses and governments, and developing metrics for measuring progress and establishing standards, which are needed for effective implementation.[36]

Robust and transparent data and analysis are needed to provide detailed information on resource flows within and between organizations and government, as well as with the public, to facilitate better collaboration to implement circular interventions; see case study 14.

Making this information and data available can encourage a culture of evidence-based decision-making and collaboration across businesses and government departments and provide the information needed for developing effective legislation and policies.[37]

WORKING IN PARTNERSHIP WITH OTHERS

The GEF should collaborate and engage in partnerships that facilitate innovation and attract finance for circular economy solutions, for example the Platform for Accelerating the Circular Economy[38] (of which the GEF is a member) and the Climate Technology Centre and Network,[39] which promotes the accelerated transfer of environmentally sound technologies for low-carbon and climate-resilient development at the request of developing countries.

The GEF should also promote more widespread adoption and replication through data sharing, demonstration projects and awareness-raising, for example with the Global Alliance on Circular Economy and Resource Efficiency, the World Business Council for Sustainable Development, the Ellen MacArthur Foundation, and Circle Economy,[40] a consultancy that aims to accelerate implementation of the circular economy.

ANNEX 1: CIRCULAR ECONOMY INTERVENTIONS

INTERVENTIONS WITHIN THE BIOLOGICAL CYCLE

Intervention 1. Reducing emissions from crop production through regenerative agriculture

Current food production and consumption systems emitted 18 gigatons of carbon dioxide equivalent ($GtCO_2e$) per year in 2015, representing a third of global anthropogenic greenhouse gas (GHG) emissions. Agriculture and land-use or land-use change activities were responsible for approximately 70% of these emissions, with the remainder linked to food supply chain activities.[41] Regenerative agriculture is a nature-based farming system that deploys practices such as cover crops, crop rotation and minimal tillage to reduce impacts from agriculture. It also incorporates techniques such as in-farm fertility management (using compost and green manure instead of synthetic fertilizers[42]), improved crop varieties (e.g. nitrogen-fixing crops), agroecology, agroforestry, permaculture, organic agriculture, biochar addition, and ecologically based integrated pest management. (See Annex 2 for definitions of these and other technical terms.) These practices protect or improve soil health and fertility, conserve cropland biodiversity, improve water retention and provide nature-based control of weeds, pests and diseases.

Regenerative agriculture aligns with the circular economy by shifting from an extractive, linear farming system that prioritizes crop yield to a circular approach that enhances synergies between yield, soil health, biodiversity conservation and water management. Key elements of the circular economy relevant in regenerative agriculture include the redesign of how crops are produced to phase out GHG-intensive inputs (e.g. fertilizers), the prioritization of regenerative sources through nature-based solutions, the use of waste such as manure and crop residues as resources, and the preservation of soils.

Regenerative agricultural practices facilitate GHG mitigation by avoiding emissions related to external inputs (e.g. chemicals, machinery), enhancing the soil's ability to absorb and retain carbon, eliminating emissions related to burning of crop residues (e.g. black carbon, carbon dioxide), and reducing the carbon intensity of crop production through increased yield. Regenerative agriculture could mitigate between 14 and 22 $GtCO_2e$ between 2020 and 2050 depending on the level of adoption globally.[43] However, there are concerns about achieving climate benefits due to uncertainties in soil carbon sequestration capabilities from regenerative agricultural practices, challenges in accurately measuring carbon fluxes, and difficulties in scaling and wide adoption.[44]

Apart from the climate benefits, regenerative agricultural practices improve soil health, thus reducing land degradation. This leads to better water management and reduced water pollution – for example, through cover cropping – and helps eliminate the use of harmful chemicals. These benefits also typically include improved biodiversity conservation in related ecosystems. Reduced dependence on external inputs and improved management practices also increase crop production systems' resilience, thereby strengthening their ability to adapt to climate change. Socioeconomic benefits include increased food and nutrition security, better health due to decreased use of harmful chemicals, and increased farmer income and welfare. The return on investment from regenerative agriculture is also expected to be significant: spending US$78–116 billion on regenerative agriculture is estimated to yield US$2.3–3.5 trillion in lifetime operational cost savings.[45]

CASE STUDY 1: PROMOTING AGROECOLOGICAL PRACTICES IN ARGENTINA[46]

Agricultural practices involving monoculture and heavy use of agrochemicals have had severe effects on soils in Argentina, including diminished nutrients and organic matter and, consequently, diminished ability to sequester carbon.

To address this problem, the Union of Land Workers (UTT) promotes agroecological practice as an alternative to the chemical-intensive agricultural model. UTT encourages its members to use biological products obtained from living organisms with properties beneficial to the soil (bio-inputs) and diversified crop varieties instead of pesticides and transgenic seeds.

UTT undertakes advocacy for improved legislation, helps secure access to land for farmers, and provides micro and soft loans to smallholder farmers to facilitate quick adoption of agroecological practices. It also carries out training, undertakes capacity-building initiatives, has factories for manufacturing natural pesticides and provides diversified markets for selling farm products.

UTT activities have reduced synthetic external inputs and improved soil quality, thereby mitigating greenhouse gas emissions and sequestering carbon. Through UTT activities, 250 family farms now produce sustainably on 300 hectares. A 20% yield increase, an 80% saving in farm expenditures and a doubling of revenues have been reported. Furthermore, the farm produce is more nutritional and contains no agrochemicals.[47]

Intervention 2. Improving resource efficiency in livestock production

Current livestock production is mainly linear in nature, typically using high levels of material inputs and resulting in substantial waste generation and GHG emissions. Emissions from livestock supply chains (production, processing, transportation, waste management, etc.) totalled about 8 $GtCO_2e$ in 2010,[48] representing a significant portion of overall food systems emissions. Estimates indicate that emissions from the sector range from 12% to 18% of global GHG emissions.[49] Emission sources include enteric fermentation (39%), feed production (45%),[50] product processing, transportation, and waste management (16%).[51] Livestock emissions are significant in Global Environment Facility (GEF) recipient countries. The carbon intensity[52] of meat production in Latin American, African, and South/Southeast Asian countries often exceeds 80 tCO2e per ton of meat produced – approximately twice as high as in North America and Europe.[53]

Circular economy strategies can address emissions related to feed production, product processing, transportation and waste management. Circular solutions with climate benefits include:

- Use of agricultural crop residues or those unsuitable for human consumption as livestock feeds
- Use of less fertile soils for animal grazing, consequently providing manure to soils from livestock waste (reducing the need for synthetic fertilizers)
- Improved management of rangelands to enhance carbon sequestration
- Anaerobic digestion of livestock waste to produce energy, thereby providing an alternative to firewood (reducing forest degradation and eliminating black carbon emissions[54])

Other strategies include adopting livestock management practices that improve resource-use efficiency and reduce GHG emissions, such as managed grazing,[55] feed and dietary management,[56] selective breeding,[57] improved herd management,[58] and better manure management.[59]

Implementing the above strategies requires integrating crop and livestock management systems. It also involves cooperation between multiple businesses across the food sector to effectively close nutrient, energy, carbon and other resource cycles. Addressing production-related livestock emissions through the above strategies can mitigate up to 2.5 $GtCO_2e$ by 2050 or a third of emissions with respect to the baseline scenario.[60]

Beyond the climate benefits, circular interventions in the livestock sector will also reduce land degradation, as animal manure application can improve soil nutrients, texture and structure. This is particularly beneficial when less productive lands are used for animal grazing. Conversion of animal manure to energy can prevent forest degradation and conserve associated biodiversity. This will also mitigate air-pollution-related and black carbon emissions from biomass burning for cooking and heating. Reduced inputs of synthetic chemicals will help minimize pressure on water resources and associated biodiversity and ecosystem services caused by chemical pollution. The reduced dependence on external inputs and improved management practices will also increase the resilience of livestock production systems, thereby strengthening the ability of these systems to adapt to climate change. Socioeconomic benefits include increased productivity leading to enhanced food security and improved farmer income.

CASE STUDY 2: BIOGAS PRODUCTION FROM LIVESTOCK MANURE MANAGEMENT IN KENYA[61]

Many households and smallholder farmers in Kenya depend on firewood and expensive fossil fuels for cooking energy, resulting in indoor and outdoor air pollution and deforestation.

The Kenya Biogas Programme (KBP), a constituent of the Africa Biogas Partnership Programme, has worked to resolve these problems and promote food security, clean and sustainable energy, and environmental conservation. KBP is a public-private partnership between development partners Hivos, the Netherlands Development Organisation and the Directorate-General for International Cooperation of the Netherlands Ministry of Foreign Affairs.

The programme provides biodigesters to individual households, which can use them to process manure from livestock. The energy generated provides fast and smokeless cooking. Unwanted slurry from the digestion process provides organic fertilizer, thereby reducing the need for synthetic fertilizers.

To overcome financial, economic, technology and capacity barriers, the KBP created the Biogas Marketing Hub to build an effective marketing and business development structure for the biogas sector. The Biogas Marketing Hub provides biodigester information, training, sales, and extension and marketing efforts aimed at organized target markets to promote adoption and implementation. The programme works with financial institutions and cooperatives to access credits for households and links biogas users to carbon credit sales to subsidize the biodigester costs.

Since its inception, the KBP has constructed over 17,000 biodigesters, reduced almost 300,000 tCO_2e, prevented deforestation in 23,000 hectares of land, saved almost 300,000 tons of biomass, and created 107 full-time jobs plus part-time unskilled day labour.

Intervention 3. Shifting to alternative protein sources and sustainable diets

The exponential growth in meat consumption since the 1960s is a major driver of growth in emissions from livestock. This trend will continue under business-as-usual scenarios, with meat consumption projected to grow by up to 80% by 2050 due to increasing income and population in developing and emerging economies.[62]

Apart from improving resource efficiency in the sector (Intervention 2), the circular economy also promotes a shift from a high intake of meat protein to healthier and more sustainable protein sources. A healthy diet ensures "an optimal caloric intake and consist largely of a diversity of plant-based foods, low amounts of animal source foods, contain unsaturated rather than saturated fats, and limited amounts of refined grains, highly processed foods and added sugars".[63] In addition, "sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources."[64]

Healthy and sustainable diets align well with the circular economy. They ensure that resources are used efficiently in producing food and that produced foods (meat, grains, fruits and nuts) are used judiciously instead of resulting in excessive calorific intake harmful to human health and the environment. Producing and consuming plant-based protein, from beans, pulses, lentils and other sources, further supports the circular economy and climate change mitigation by nourishing soils through nitrogen fixing and represents a less carbon- and land-intensive approach than meat production.[65]

A transition to plant-based diets with less animal-sourced foods and in line with standard dietary guidelines could reduce food-related emissions by 29%–70% compared to a 2050 reference scenario of around 11 $GtCO_2e$ in emissions per year.[66] The Intergovernmental Panel on Climate Change (IPCC) estimates the technical mitigation potential of dietary change to range from 0.7 to 8.0 $GtCO_2e$ per year by 2050.[67] Adopting plant-rich, low-meat diets[68] increases the likelihood of meeting the 1.5°C Paris target.[69] Apart from climate benefits, plant-based diets could free up to several million square kilometres of land used in grain production; reduce associated forest degradation, chemical and water pollution, and biodiversity loss; improve food security; and deliver significant health benefits (related to the reduced consumption of meat).[70] Plant-based diets could reduce global mortality by 6%–10% by 2050 if adopted widely.[71]

A transition to a sustainable and healthy diet will look different in different countries. For example, while high-income countries need to curb meat protein intake, low-income countries may need to boost it to ensure optimal calorific levels.[72] It is, however, crucial that low- and middle-income countries curb trends towards meat overconsumption as seen in the developed world. While meat consumption in arid, cold or mountainous areas may be efficient and appropriate at a subsistence level, and thus provide a sustainable food source, such instances are limited and generally specific to low-population contexts and specific geographies.

CASE STUDY 3: REDUCING MEAT CONSUMPTION THROUGH DIETARY GUIDELINES IN CHINA[73]

A significant proportion of global meat consumption occurs in China: 28% of the world's meat, including half of all pork. To improve public health, the Chinese Government in 2016 issued dietary guidelines aimed at cutting meat consumption in the country by 50% by 2030. The guidelines, prepared by the country's health ministry, recommend 40g–75g of meat per person per day, a nearly 50 kg reduction in per capital consumption compared with 2014 levels.

While the dietary guidelines' focus was public health improvement, their successful implementation would provide significant climate and environmental benefits. Carbon dioxide emissions from China's livestock industry are expected to reduce from the projected 1.8 billion tons to 0.8 billion tons in 2030 if the guidelines are followed. The adverse impact of livestock production on water, land and energy use will also decrease.

A 2018 survey of mainly tier-one Chinese cities indicates that pork and poultry consumption is declining, with diets shifting towards plant-based meat (soy products), fish and seafood. More than 70% of respondents specified that meat reduction campaigns made them more aware of the benefits of eating less meat. The plant-based meat market is now projected to grow from $10 billion in 2018 to nearly $12 billion by 2023.

Intervention 4. Reducing food losses from harvest to processing

A significant portion of food produced is lost before reaching retailers or consumers due to a lack of adequate infrastructure, including storage and processing facilities, demand uncertainties and inadequate market linkages.[74] Roughly a quarter of produced food is lost at the production, handling, storage and processing stages, with much of this occurring in GEF recipient countries.[75] Food loss and waste were responsible for 8%–10% of global GHG emissions during 2010–2016,[76] with a global carbon footprint of 4.4 $GtCO_2e$ per year. If this were a country, emissions from these sources would make it the third-largest emitting nation.[77]

Circular economy interventions include preserving and extending the value and shelf-life of produce through storage, handling, processing and transportation infrastructure and improving supply chains and procurement channels to allow efficient transfer of products between producers, processors and consumers (e.g. through the use of technology platforms that connect farmers and potential buyers or through contract farming, direct sourcing or collection centres).[78] Other circular interventions include using inedible farm residues such as straws, stalks and prunings for compost, bioenergy, biochar, livestock fodder or construction instead of open burning, which is otherwise a common practice.[79]

The World Resources Institute estimates that reducing the current level of food loss and waste by 50% will cut associated GHG emissions by 1.5 $GtCO_2e$ per year by 2050, representing about a 10% reduction from projected baseline agricultural emissions in that year.[80] IPCC analysis indicates that food losses and waste reduction measures can potentially mitigate between 0.8 and 4.5 $GtCO_2e$ per year.[81]

Addressing food loss and waste provides other environmental benefits, including reduced land degradation and enhanced water security. A land area the size of China and a quarter of all agricultural water use is required to produce lost and wasted food every year.[82] Maximizing the use of produced food will also reduce the amount of chemicals used in agriculture and minimize food production impacts on biodiversity, especially if food production employs regenerative agriculture approaches (Intervention 1). Reducing food loss and waste would also enhance food security, improve agricultural stakeholder income, and create jobs across food supply chains. It would also prevent the economic, environmental and social cost of wasting food, estimated at around US$2.6 trillion.[83]

CASE STUDY 4: COLDHUBS: A SOLAR-POWERED COOLING-AS-A-SERVICE SOLUTION IN NIGERIA[84]

Post-harvest loss of vegetables and fruits is significant in Nigeria – up to 50% of annual production. This is due to a lack of infrastructure, deteriorating roads, unstable energy sources, lack of access to technology and inadequate smallholder farmer finance.

The ColdHubs solution is a pay-as-you-store modular solar-powered walk-in cold room created by a private entrepreneur in collaboration with the Deutsche Gesellschaft für Internationale Zusammenarbeit to address some of these problems. The cold storage facilities, which are installed close to major food production and consumption centres (farms and markets), provide farmers with the opportunity to store their vegetables, fruits and other perishable food in cold rooms, thereby extending their freshness from 2 days to about 21 days. The pay-as-you-store model allows farmers who cannot afford expensive storage facilities to preserve their produce at an affordable price.

In 2019, 24 operational ColdHubs prevented 20,400 tons of fruits and vegetables from perishing, thereby saving 462,528 kg of carbon dioxide emissions, increasing the household income of 3,517 small farmers, retailers and wholesalers by 50% and creating 48 new jobs. It has also helped reduce malnutrition and support gender objectives, given that a large proportion of users are women.

Intervention 5. Avoiding food waste at the retailer and consumer levels

While a significant proportion of food loss occurs in developing countries prior to getting into the market, most wastage of food (at retailer and consumer levels) occurs in the developed world – more than 40%.[85] However, a substantial amount of food waste still occurs in GEF recipient regions. Approximately 15% of produced food is wasted at the distribution, market and consumption stages in industrialized Asia, North Africa, and West and Central Asia. This figure is 12%, 9% and 7% in Latin America, South/Southeast Asia, and Africa, respectively.[86]

Circular interventions include rethinking business models to ensure that produced foods are consumed, for example by developing markets for surplus food, products nearing their expiry dates or foods categorized as imperfect. Other interventions include:

- Collaboration within supply chains to standardize labelling to provide accurate information on usability of food to consumers
- Engagement and coordination between retailers and suppliers to address production and supply priorities and allocation[87]
- Incorporation of digital technologies to improve inventory management and prevent wastage
- Alternative packaging design to preserve food (e.g. resealable packaging)

Beyond the significant climate benefits, food waste reduction provides other environmental benefits, including reduced land degradation, enhanced water security and biodiversity conservation, and reduced chemical use, by reducing the need to produce more food.

CASE STUDY 5: TEKEYA APP: USING MOBILE APP TECHNOLOGY TO REDUCE FOOD WASTE IN EGYPT[88]

A significant amount of food is lost or wasted in the Near East and North Africa (NENA) region, including Egypt. About 250 kg of food per capita is lost or wasted annually in the region, with the loss of up to 55% of fruits and vegetables in Egypt alone. This situation results in significant impacts in the NENA region, including using an estimated 42 km^3 of water (roughly half of the volume of Lake Geneva) and 360 million hectares of land to grow and distribute food that is ultimately lost or wasted.

To reduce food waste, the Tekeya mobile app connects consumers to hotels, restaurants, groceries, bakeries and other food retailers willing to sell their surplus food or food close to its expiry date at a reduced price or donate it to charities.

The Tekeya app is being used by 405 businesses, has saved 3,800 meals, and is estimated to have reduced carbon dioxide emissions in Egypt by over 4 tons. It has also offered additional revenue streams for food companies and helped create brand exposure and public awareness on food waste. After its initial success, it is being expanded to several provinces in Egypt. There are also plans to expand it into the rest of the NENA region.

Intervention 6. Closing the loop on organic waste

Although reducing food loss and waste should be prioritized, some organic waste may still occur along the food supply chain. Further, other non-food organic waste (e.g. greens from gardens, lawn trimmings, tree pruning) is usually generated. Indeed, a significant proportion (44%) of waste composition globally is organic.[89] Estimates of organic waste generation in GEF recipient regions usually exceed the global average, with organic waste in some regions rising to 58% of the total waste stream.[90] Wastewater is also rich in nutrients and organic content and is generally not adequately captured and returned to productive use in many countries. Only 8% of generated wastewater in low-income countries is captured and treated. This number is 28% and 38%, respectively, in lower-middle-income and upper-middle-income countries.[91] Landfills and wastewater are responsible for 19% of global methane emissions,[92] with GEF recipient countries accounting for more than half of these emissions.[93]

Possible circular measures include converting organic waste to biogas or biofuel (which can help meet energy demands and reduce dependence on firewood and fossil fuels) and digesting organic waste into compost or manure for use in agriculture (to reduce reliance on fossil fuel-based synthetic fertilizer). Other measures include extraction of nutrients (nitrogen and phosphorus) from wastewater for agriculture, thereby reducing methane and nitrous oxide emissions.

Implementing these interventions will require an effective waste collection, separation and processing system, as well as wastewater management infrastructure. Depending on the desired scale, such systems could be decentralized to cover households, communities or large-scale treatment plants.

The success of these interventions will further require the stimulation of demand. Urban and peri-urban agriculture could play a critical role in creating local closed-loop systems and help avoid long-distance transportation and related emissions.[94] It also reintroduces productive landscapes into city design and development, provides climate mitigation by sequestering carbon (especially when it incorporates urban agroforestry[95]), reduces emissions related to food miles, and minimizes fertilizer and energy consumption (through the reuse of urban waste as manure).[96] This approach provides climate change adaptation and disaster risk reduction benefits by enhancing rainwater infiltration, allowing flood zones to be put to productive use, reducing urban heat island effects and minimizing urban poor vulnerability by creating food and income sources.[97]

Closing the loop on organic waste coupled with urban and peri-urban agriculture provides other environmental benefits beyond climate change mitigation and adaptation. Reduced application of synthetic fertilizers can decrease agricultural-induced water pollution. The management and reuse of urban wastewater minimizes nitrous oxide emissions and the associated impact on the ozone layer[98] and frees freshwater resources for higher-value uses. Diverting organic waste from landfills increases the lifespan of waste disposal facilities and saves valuable land resources. It also reduces leachates and the pollution of groundwater resources. Nutrient recovery from wastewater also offers a sustainable alternative to scarce nutrients such as phosphorus, predicted to become insufficient or even exhausted over the next decades.[99] Urban and peri-urban agriculture enhances the biodiversity of urban areas; improves food and nutrition security;[100] and contributes to improved well-being, social inclusion and gender equality, as 65% of urban farmers are women.[101]

CASE STUDY 6: DECENTRALIZED SYSTEM FOR PRODUCING COMPOST FROM ORGANIC WASTE IN SAO PAULO, BRAZIL[102]

The city of Sao Paulo, Brazil, with a population of about 12 million, generates a significant amount of organic waste that is not treated or recovered. Less than 2% of municipal solid waste, comprising 51% organic materials, was separately collected and recycled in 2014. A significant portion of the organic waste comes from over 900 street markets, 69 city parks, and 3,900 squares and green areas, generating about 120,000 tons of organic waste every day. The municipality also generates an additional 39,000 tons of organic material annually from tree and plant pruning.

Given the complexity of establishing a centralized waste management system, the city launched a network of low-tech decentralized composting facilities to convert organic waste into manure. This started as a pilot, which was then carefully scaled up based on experience and success. Compost from street markets is used to maintain public spaces in the city. Also, the city's Composta Sao Paulo initiative encourages voluntary home-composting activities among residents, with about 5,000 families participating in 2015 and 10,000 joining an educative online platform for home composting. The initiative also includes an urban garden programme to promote crop production among city dwellers. Furthermore, Escolas Mais Organicas was launched, which provides education and promotes composting activities among participating municipal schools.

These initiatives are founded on the city's master plan for managing solid waste, *Planes de gestión integral de residuos sólidos*, which specifically aims to reduce waste disposal by separate collection and recycling, including separate collection of organic waste; gradual development of treatment and recycling facilities; and continuous communication activities to raise awareness about organic waste. The initiatives also involved collaboration with external organizations such as C40 and the Climate and Clean Air Coalition, focusing on reducing short-lived climate pollutant emissions, including methane and black carbon.

As a result of the decentralized composting for street markets, about 1,920 tCO_2e emissions were prevented annually, representing an 87% reduction from the business-as-usual scenario. The initiatives also provide health benefits associated with improved market sanitation. Job creation and improved waste logistics within the city are also added benefits of the initiatives.

Intervention 7. Deploying bio-based materials and accelerating the bioeconomy

Apart from being primarily linear, many of today's infrastructure and production processes are based on fossil fuels and finite mineral feedstock. The energy use associated with the extraction and processing of these materials leads to significant GHG emissions: 62% of the estimated 50.9 GtCO_2e of global emissions in 2017 relate to material extraction and processing and goods manufacturing.[103]

Increased use of bio-based materials (substances mainly derived from living matter or biomass) for the manufacturing of products will promote circular economy approaches by prioritizing renewable feedstock. It will also align with the "design for the future" element of circular economy strategies by changing the fundamental materials that go into product design. Also, organic waste from these products can become feedstock for new products, thereby promoting waste as a resource.

Examples of circular interventions include using wood (e.g. cross-laminated woods), bamboo products, green roofs, plant fibres and biomass aggregates in buildings and construction to displace cement and metals.[104] Cross-laminated woods can potentially save 62% of mineral construction materials used in buildings while offering carbon sequestration.[105]

To significantly accelerate the bioeconomy, interventions will need to embrace industrial biotechnology and advanced technologies such as synthetic biology, in which enzymes, microorganisms or the programming of metabolic processes in biological systems are used to make bio-based products from biomass, organic waste and wastewater.[106] Examples include (i) the manufacture of bioplastics, packaging, leather and textiles from plant fibres;[107] (ii) bio-cement production with marine bacteria;[108] and (iii) on-site manufacturing of construction materials using microorganisms.[109]

Accelerating the bioeconomy has significant GHG mitigation potential by displacing carbon-intensive materials, thus reducing emissions from related industries. For example, substituting conventional building materials with wood can reduce construction phase emissions by 69%.[110] Further, between 1 and 55 Mt of carbon dioxide can be captured annually by buildings constructed from wood.[111] Widespread adoption of bioplastics instead of petroleum-based plastics can mitigate between 0.9 and 3.8 GtCO_2e between 2020 and 2050.[112] The full mitigation potential of expanding the bioeconomy ranges from 1 to 2.5 GtCO_2e emissions per year by 2030.[113]

Because bio-based materials are compostable, they cause little harm compared with alternatives. It is, however, essential that the sources of bio-based material do not compete with food or drive negative impacts on biodiversity, land, water or forests. Moreover, the expected emission reduction also needs to be balanced against possible GHG emissions from the indirect land-use change[114] and energy use of some industrial biotechnology processes.

CASE STUDY 7: PIÑATEX: BIO-BASED LEATHER ALTERNATIVE FROM THE PHILIPPINES[115]


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Traditionally, leathers are made either from animal hides or synthetic fossil fuel alternatives. These conventional options are associated with negative impacts, including greenhouse gas emissions; heavy use of resources, including land, water and fuel; use of toxic chemicals (including persistent organic pollutants); high generation of waste from the tanning process; and pollution of terrestrial and aquatic environments from synthetic materials.

Inspired by the cradle-to-cradle approach, Piñatex is a commercially available bio-based alternative to traditional leathers made from waste leaves from pineapple farming. It is an example of prioritizing regenerative resources, using waste as a resource, and applying design thinking to avoid the negative environmental impacts of traditional materials. Biogas and organic fertilizers are by-products of the bio-based leather production process, providing added climate and environmental benefits. The product is currently being used in apparel, footwear and furnishing, including by global leading brands, as well as in cars and aeronautic upholstery. There are plans to expand into other countries to capture about 13 million tons of waste generated from pineapple farming globally.

Because the product is made from the by-products of the fruit industry, which are typically discarded or burned, it creates an extra income source for farming communities or cooperatives, which Piñatex works with directly. It also helps enhance gender equity, given the high percentage of women participating in pineapple farming.

INTERVENTIONS WITHIN THE TECHNOLOGICAL CYCLE

Intervention 8. Making the renewable energy transition circular

A transition from fossil fuels to renewable energy is essential to decarbonize the energy sector and mitigate climate change. This is already happening. The share of renewable electricity rose by 6% to reach almost 27% of global electric power in 2019, with wind and solar photovoltaic (PV) technologies accounting for 64% of the increase.[116] Renewables are now the cheapest electricity source and are projected to grow significantly by 2040, mainly driven by solar energy.[117]

However, renewable energy-based low-carbon electricity, such as through wind and solar PV, is more mineral-intensive than fossil fuel-based electricity. Projected future growth will significantly increase mineral demands.[118] For example, graphite, lithium and cobalt production will require a 450% increase from 2018 levels by 2050 to meet energy storage demand.[119] But the mining and processing of these minerals is energy intensive, contributing to GHG emissions. For example, aluminium, graphite and nickel production for energy technologies is projected to account for 1.4 $GtCO_2e$ by 2050.[120] Mining and processing also come with significant environmental impacts, including land degradation, deforestation, water pollution, threats to biodiversity, and chemical and waste contamination.[121]

While the overall GHG emissions from renewable energy production are significantly lower than from fossil fuel-based energy, the circular economy offers an opportunity to further reduce climate and other environmental impacts. Measures include using renewable energy sources for mining operations[122] and designing renewable energy infrastructure (solar and wind power, and associated batteries) for longevity and ease of reuse, repurposing, repair and recycling, for example through modular design. It is crucial to dramatically scale up the recycling of solar panels and wind turbines, including the recovery of critical minerals at the end-of-life of renewable energy infrastructure.[123] It is projected that 78 million tons of solar panels will reach their end-of-life by 2050, and the world will be generating about 6 million tons of new solar e-waste annually.[124] Circular business models, such as products-as-a-service, the sharing economy and product take-back, can help ensure that businesses retain ownership of products and assets and can recover valuable minerals from them at the end of their life.

Estimates of climate benefits of circular interventions in the renewable energy sector are scarce. One analysis indicates that the secondary production of 100,000 tons of aluminium through recycling, for instance, emits 4.6 Mt of carbon dioxide, compared with almost 15 times the emissions when produced from virgin materials.[125] Circular measures will also enhance climate resilience[126] and adaptation by reducing dependence on mines that are vulnerable to climate change.[127] Other co-benefits include decreased environmental impacts of the mining and processing of raw materials (e.g. reducing land degradation, deforestation, water pollution, biodiversity threats, and chemicals and waste contamination), as well as job creation and economic growth. It is estimated that the value of recovered materials from the projected 78 million tons of solar panel waste expected by 2050 could be worth more than US$15 billion if fully injected back into the economy.[128]

CASE STUDY 8: CRADLE-TO-CRADLE CERTIFIED SOLAR PANELS IN LITHUANIA[129]

SoliTek is a Lithuania-based company that builds solar panels that are cradle-to-cradle certified. Its solar panels have been assessed for environmental and social performance across five sustainability categories – material health, material reuse, renewable energy and carbon management, water stewardship, and social fairness – and found to be safe and healthy for people and the environment. The production, use and end-of-life management also significantly eliminates waste, uses clean energy, protects water resources and respects human and natural systems.

SoliTek solar modules are designed to have a long lifespan and are produced using solar and geothermal energy. The company also recycles the majority of the waste generated during manufacturing. Furthermore, SoliTek is a partner in the European Union Horizon 2020 CABRISS project[130] focused on technologies to recover and reuse indium, silver and silicon in solar panels, including through industrial symbiosis (see Intervention 14). The CABRISS project will collect 90% of photovoltaic (PV) waste in Europe, retrieve 90% of high-value raw materials from solar panels, and manufacture PV cells and panels from recycled raw materials.

SoliTek is also part of the CIRCUSOL (Circular Business Models for the Solar Power Industry) Innovation Action project, which aims to deliver environmental, economic and social gains by shifting to circular approaches in solar power manufacturing and use. The envisioned product–service system model would provide solar power generation and storage to users as a service, while the supplier would remain the owner of the solar PV and batteries and would be responsible for their optimal functioning and their recycling or for the creation of a second life after the first life.

Intervention 9. Making the most of widely used materials

Our world is built on several essential materials, including concrete (the most used material globally), wood (Intervention 7), metals, plastics, paper and silicon (glass). However, the production and use of these materials creates enormous waste streams and contributes to climate change. For example, the greenhouse gas emissions associated with the production, use and disposal of materials including plastic, rubber, wood products, cement, iron, and other metals and minerals was 11.4 $GtCO_2e$ in 2015. [131]. Further, the cumulative emissions from the production of steel, cement, aluminium and plastics are expected to reach 649 billion tons of carbon dioxide by 2100.[132]

Many of these materials are not recycled at their end-of-life, leading to significant waste volumes. The world generates 2 billion tons of urban waste annually, and this figure is projected to grow to 3.4 billion tons by 2050. The rate of waste generation is increasing at the fastest pace in Sub-Saharan Africa, South Asia, and the Middle East and North Africa, with about 20% of waste streams in low-income countries comprising recyclable materials (metals, plastic, glass, paper and cardboard).[133] In industry, approximately one-tenth of the paper, a quarter of the steel and half of the aluminium produced annually is discarded.[134]

The circular economy provides opportunities to reduce the environmental and climate impacts of these materials by altering production processes. For example, embracing renewable energy instead of fossil fuels for material production, or employing hydrogen-based steel making using direct reduction, can significantly reduce GHG emissions – an up to 90% cut in carbon dioxide emissions compared with traditional blast furnaces.[135] Also, incorporating efficiency measures into the production processes can significantly eliminate waste generation.[136] Other interventions include redesigning products that use these materials; for example, reducing the thickness of steel packaging will reduce the amount of metal needed and increase production rates, with consequent emissions reduction.[137] Prioritizing regenerative raw materials, such as bio-based plastics, can also reduce associated emissions (Intervention 7). For example, 1 kg of bio-based plastics was shown to have a net removal of 2.2 kg of CO_2e from the atmosphere compared with the same type of fossil fuel-based plastic, which emits 1.8 kg CO_2e per kilogram. [138]

It is also essential that products containing these materials are designed for longevity, ease of reuse, repurposing, repair, disassembly, remanufacturing and recycling. The carbon footprint of recycled materials is significantly lower than that of similar materials from primary resources.[139] Hence, increasing the recycling rate for many of these materials (e.g. through urban mining[140]) will reduce waste volumes and provide less-carbon-intensive secondary raw materials to substitute primary extraction. Deploying business models and collaborations to promote recycling in the value chain (e.g. buy-back schemes for used materials), creating secondary markets for reusable materials and products, and incorporating the informal sector into waste management (case study 9) are also important circular interventions.[141]

Deploying circular economy strategies in material production and use could reduce emissions from cement, steel, plastic and aluminium by 40% in 2050.[142] It would also reduce the other environmental impacts associated with the extraction, production and use of these materials, including water pollution, land degradation and biodiversity loss.[143] The circular economy can also reduce air pollution associated with the emissions of nitrous oxide, particulate matter (including black carbon) and unintended persistent organic pollutants caused by poor waste disposal measures. Furthermore, circular measures, especially recycling, present significant job creation and economic opportunities.[144]

CASE STUDY 9: INTEGRATING THE INFORMAL SECTOR INTO MUNICIPAL SOLID WASTE MANAGEMENT IN INDIA[145]

The lack of adequate infrastructure for collecting and separating waste is one of the major barriers to reusing and recycling materials in many developing countries, including India. Informal waste pickers play an essential role in this regard but are not adequately recognized as part of the economy, limiting their contribution to circular economy goals.

The SWaCH waste picker cooperative provides a model that helps integrate informal waste pickers into the economy while generating significant climate, environmental and socioeconomic benefits. It is a member-owned trade union that offers decentralized door-to-door waste collection and separation service and an opportunity for recyclable fractions to be sold as scrap and reused, while non-recyclable fractions are disposed of through the municipal garbage management system. The trade union provides access to insurance, financial, legal and educational support to its members. It also collaborated with the Pune Municipal Corporation to integrate the waste pickers into the municipality's waste collection system, thereby formalizing their status and reducing the cost of waste handling.

One of the catalysts for SWaCH success was a new Municipal Solid Waste (MSW) law passed in Pune requiring waste separation, door-to-door waste collection, and waste processing instead of dumping, highlighting the importance of legal and policy frameworks in transitioning to a more circular economy.

SWaCH collects over 850 tons of MSW per day, of which around 150 tons are recycled and 130 tons composted. E-waste collection points installed in private and government organizations, schools, and colleges also support the repair and recycling of electronic products. SWaCH has integrated 3,500 waste pickers serving more than 3 million people. Avoided GHG emissions from SWaCH activities in 2018 were estimated at around 185,000 tons CO_2e, equivalent to removing the annual emissions of about 40,000 passenger vehicles. Because over 80% of SWaCH members are women, the model also contributes to achieving gender equality objectives.

Intervention 10. Incorporating circular design in construction

Increasing population, wealth and migration to urban areas are driving rapid growth in the construction of residential and commercial buildings and infrastructure globally, including in many low- and middle-income countries.[146] The global building stock is expected to double in area by 2060, with more than 50% of the increase expected by 2040, mainly in Asia and Africa.[147] This trend means an increase in the extraction of raw construction materials and, consequently, associated GHG emissions.

Materials for buildings construction and subsequent operation were responsible for 38% of global energy-related carbon dioxide emissions in 2019, with 10% due to embedded emissions (i.e. the emissions related to the production of materials and the construction process).[148] Cement production alone is responsible for 4% of global carbon dioxide emissions,[149] and cement is the most used construction material globally.[150]

Circular economy principles can help reduce embedded and operational emissions.[151] Measures include optimizing building design for long service time, reducing energy use during a building's life cycle, and facilitating easy disassembly to recover and reuse valuable materials at the end of a building's life.[152] For example, passive design strategies incorporating architectural features to reduce energy consumption, as well as modular design and off-site construction, can minimize waste in the construction process (about 15% of building materials are wasted in construction[153]) and increase the ease of disassembly, reuse and recycling. Nature-based solutions such as green roofs (Intervention 7) can also reduce the energy use of buildings.[154] Digital technologies can enhance building design and resource management, and 3D printing can improve construction material efficiency.[155]

Alternative forms of concrete and building materials that create fewer GHG emissions and improve resource efficiency can also be deployed. This may involve using demolition waste,[156] discards from other processes, or renewable materials to create products with fewer embodied emissions. Examples include flyashcrete, papercrete, hempcrete, ashcrete and geopolymer concrete.[157] Urban mining to harvest waste as well as secondary and end-of-life building materials can also play a significant role.[158] A new generation of concrete technology is also being designed that requires less steel reinforcement (thereby reducing related emissions) and is engineered to maximize carbon dioxide absorption.[159]

Estimates indicate that passive housing design can reduce individual emissions by 0.5 tCO_2e per year, which is very significant when multiplied by population. It is estimated that the reduction of emissions in UK buildings through design optimization and alternative forms of concrete will reach more than 40 $MtCO_2e$ by 2032.[160] Using alternative cement is expected to mitigate between 7.9 $GtCO_2e$ and 16.1 $GtCO_2e$ of emissions between 2020 and 2050 if widely adopted worldwide.[161] Improved building design, such as passive housing, increases climate resilience and adaptation to events such as heatwaves. Green roofs reduce urban heat islands, improve air quality[162] and could reduce up to 1.1 $GtCO_2e$ in emissions globally by 2050.[163]

Increased resource-use efficiency through this intervention will reduce waste disposal and associated chemicals and waste pollution. The water pollution, land degradation and biodiversity impacts of extracting virgin construction materials are also reduced with increased recycling of building materials and substitution with alternative materials. Off-site construction can also help improve labour conditions and safety, as it is easier to create a secure working environment in an assembly setting than on a construction site.[164]

CASE STUDY 10: ECOMO MODULAR BUILDING DESIGN IN SOUTH AFRICA[165]

©Ecomo Home

Ecomo homes are low-impact, low-maintenance buildings constructed using modular design and off-site prefabricated components. The design considers the proposed buildings' natural surroundings to minimize adverse environmental effects and costs during building operation. The modular design and off-site construction option provide flexibility in size, layout and functionality and allow users to adapt the building to changing requirements. The use of timber frames helps avoid the greenhouse gas emissions of carbon-intensive construction materials.

The carbon footprint of the construction and operation of an ecomo home is significantly lower than that of conventional buildings, and the use of timber provides added carbon sequestration. Each cubic metre of timber can sequester an average of about 1 tCO_2e. A logging truck carries 40 m^3 of timber, roughly the amount required to build a single-family home in North America.

Additional benefits of ecomo homes include a fast and efficient construction process, flexibility to build in a variety of locations, minimization of resource (e.g. water, energy) use during construction and operation, and generation of less waste.

Intervention 11. Incorporating the circular economy in electrification of transport

GHG from transportation is the fastest-growing emissions source, accounting for 23% of total energy-related carbon dioxide emissions globally in 2010[166] and 14% of global GHG emissions.[167] Road transport accounts for 72% of global transportation emissions and is responsible for 80% of the overall increase from 1970 to 2010.[168] Electric vehicles (EVs) that use battery-powered electric motors are among the critical solutions for the decarbonization of road transport, and their adoption has been increasing globally. The global fleet of EVs expanded significantly in the past decade and is projected to grow even more in the coming decades, with several manufacturers of internal combustion engines committing to full transition to EVs in the future.[169]

The manufacture of EVs, however, requires critical elements such as cobalt, lithium, aluminium, nickel and copper. Their mining and processing are linked to GHG emissions and other environmental degradation, including land degradation, chemical and waste pollution, forest degradation, and biodiversity loss.[170]

Incorporating circular economy principles into the manufacture of EVs can help reduce these impacts. Batteries, for instance, can be designed to last longer and be repairable, increasing their lifespan.[171] They may also be given a "second life"[172] by repurposing them for use in vehicles requiring less power (e.g. electric tricycles, airport baggage carts) and for energy storage in decentralized renewable energy to meet demands in regions with limited electricity supply.[173] Technologies are also emerging to recover important elements such as cobalt and copper from EVs and batteries at their end-of-life.[174] Embracing manufacturing designs that increase the ease of recycling of EV materials is another crucial circular economy strategy.[175] Renault has shown that both traditional cars and EVs can be designed to be recyclable and recoverable and that engines can be remanufactured.[176] Interventions will also involve developing new business models and collaborations among actors to scale up the redesign, repurposing, repair and second-life application of EV components.[177]

Incorporating circular principles into EVs will provide climate change benefits by reducing the need to mine virgin minerals. For example, an analysis indicates that between 0.8 million and 1 million tCO_2e could be mitigated by 2040 by recycling the materials used in the lithium-ion batteries of electric cars in the European Union. This equals the carbon dioxide emissions of making about 5% of global primary aluminium or the average annual production of two primary aluminium smelters.[178] An approach incorporating circular economy principles ensures that resource-efficient solutions are available for the approximately 1.2 million EV batteries projected to reach their end of first life by 2030,[179] thereby preventing disposal in landfills and possible environmental degradation and health costs.[180] It is also expected to provide employment and investment opportunities: up to €2.6 billion worth of cobalt, nickel, aluminium and lithium can be recovered by recycling EV batteries in the European Union alone.[181]

CASE STUDY 11: REUSE, RECYCLING AND REMANUFACTURING OF EV BATTERIES IN CHINA[182]

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Electric vehicle (EV) sales have significantly increased globally, including in China. This has led to a rapid increase in the consumption of valuable metals and a need to manage large volumes of used EV batteries and waste. To address these challenges, GEM Co. Ltd, an urban mining and recycling business in China, evolved from battery and electronic collection to the recycling of EV batteries, electronics waste and scrapped cars, and the recovery of rare metals such as cobalt, nickel and tungsten.

Ranked in the top five environmentally friendly companies in China, GEM Co has established several recycling plants across the country and has EV battery collection arrangements with over 280 automobile companies and battery manufacturers. The company recycles more than 4 million tons of waste resources per year and recycled more than 12,000 EV battery sets in the first six months of 2020 alone. The volume of cobalt and tungsten recycled by GEM annually equals, respectively, 100% and 5% of China's raw cobalt and tungsten. The quantity of recycled cathode materials from lithium-ion batteries for remanufacturing accounts for more than 20% of China's yearly market, and recycled germanium resources account for 6% of global output.

Chinese Government policies incentivizing recycling practices and promoting companies that are deploying technological innovation in waste treatment and recycling have helped to further GEM Co's success. GEM innovative solutions have resulted in a circular EV battery value chain involving collection, refurbishment, recycling, material circulation and battery management software to improve battery usage effectiveness and useful life. GEM Co's activities between 2013 and 2019 reduced 52 million tons of carbon dioxide, prevented soil pollution of 400,000 km^2 (equivalent to Germany and Belgium combined) and avoided pollution of 590 billion m^3 of water (greater than the volume of Lake Erie).

Intervention 12. Expanding non-motorized and shared mobility

Between 2000 and 2016, direct carbon dioxide emissions from the transport sector increased 29% globally (from 5.8 to 7.5 Gt). Emissions from this sector increased 50% in non-Organisation for Economic Co-operation and Development countries, with Asia experiencing the most significant growth of about 92% from passenger and freight transport.183 Transportation emissions are growing in countries across Africa, South Asia, East Asia and the Pacific, and Latin America.184 The IPCC projects that transport emissions could reach around 12 $GtCO_2e$ per year by 2050 without the implementation of aggressive and sustained mitigation policies.[185]

Circular mitigation measures in the transportation sector include prioritizing transportation modes that are regenerative and have limited environmental impacts. This includes (i) creating space and infrastructure for non-motorized transportation modes (walking and cycling), (ii) enhancing shared mobility (i.e. public transport: buses, trams and trains) and multimodal transport to ensure seamless interconnectivity, and (iii) promoting zero-emission transportation systems.[186] These measures will require embracing urban planning that is transit oriented and that promotes compact city development and mixed-use neighbourhoods.[187]

The adoption of new business models in the transport sector is also essential. As most private vehicles are underused, the product-as-a-service or mobility-as-a-service models can provide access to vehicles or multiple types of mobility services without a need for ownership. These business models will be facilitated by digital technologies to help match demand to supply and maximize utility rates.

Total emission reductions of up to 5, 7, 8 and 23 $GtCO_2e$ are possible globally between 2020 and 2050 by implementing walkable cities, bicycle infrastructure, carpooling and public transit, respectively.[188] The expansion of non-motorized and shared transport will deliver improved land- and resource-use efficiency and enhance air quality in urban areas[189] while also providing significant health benefits.[190] Socioeconomic benefits include reduced urban crime,[191] better road safety,[192] and improved social interaction.[193]

CASE STUDY 12: THE RABAT-SALÉ MOROCCAN TRAMWAY THROUGH A PUBLIC-PRIVATE PARTNERSHIP[194]

The Rabat-Salé tramway in Morocco was developed to address the need for adequate public transport. An unsatisfactory bus system had led to the growth of smaller-scale transport providers, with consequent emissions increase and air quality deterioration. The tramway, operated by the Société du Tramway de Rabat-Salé, now services approximately 110,000 passengers per day and provides more than 32 million trips a year, thereby significantly avoiding emissions from individual transport.

Critical success factors for the tramway were the combination of political will, financing and operational tools, including a public-private partnership, which helped create a viable large-scale investment opportunity. Project financing was through fifty-fifty government funds and international development loans. A 30-year concession agreement with Transdev from France to operate and maintain the tram system and provide capacity-building and skill transfer also played a role in its success.

These arrangements led to increased capacity and a strong sense of ownership among employees, and some of the tramline rolling stocks are now assembled in Morocco. Public perception of the tramway has also been positive, with 77% of respondents to a poll highlighting its affordability. An extension of the tramway is under way and is expected to reduce the carbon dioxide emissions of the Rabat metropolitan area by about 0.5 $MtCO_2e$ between 2020 and 2030, according to the Moroccan nationally determined contribution under the United Nations Framework Convention on Climate Change.

Intervention 13. Scaling up climate action across product value chains: textiles and electronics

The textile sector consumed 98 million tons of oil and was responsible for 1.2 billion tons CO_2e, which represented 2% of global emissions, in 2015 – more than the emissions of all international flights and maritime shipping combined.[195] By 2050, the industry will consume 300 million tons of oil and emissions and could reach close to 4 billion CO_2e if current trends continue.[196] Other environmental impacts of the textile sector include the use of more than 8,000 chemicals, including toxic persistent organic pollutants. The sector utilized 79 billion m^3 of water in 2015 (roughly equivalent to the volume of Lake Geneva), making it the second highest consumer of water globally behind agriculture and generating 20% of global wastewater. The textile sector is also responsible for the release of microfibre and microplastics into terrestrial and aquatic ecosystems and for the use of landfills due to significantly low recycling rates (average of 1% globally).[197]

In addition to the GHG emissions associated with the mining and processing of materials, the electrical and electronic products sector is a major emitter of very potent GHGs, including hydrofluorocarbons (used in refrigeration and air-conditioning) and nitrous oxide and fluorinated GHGs (used in semiconductors and LCD panels). With current trends, the emissions of these gases are projected to increase exponentially.[198] Moreover, the informal disposal or recycling of e-waste, mostly in developing countries, is a source of carbon dioxide, black carbon, mercury and unintended persistent organic pollutants.[199] A total of 98 $MtCO_2e$ were released due to the poor management of discarded fridges and air-conditioners in 2019, equivalent to about 0.3% of global energy-related emissions in 2019.[200]

Circular solutions in these sectors begins with product design. In the fashion sector, clothes can be designed and manufactured from bio-based regenerative sources (see case study 7). They could also be designed to be more durable, recyclable and based on green chemistry.[201] In the electrical and electronic sector, products can be designed to emphasize durability (instead of the current model of built-in planned obsolescence[202]), repairability, ease of disassembly and avoidance of hazardous chemicals.[203]

Circular measures also include the repair and reuse of textile and electronic products to maximize their lifespan and utility and to promote materials recovery at end-of-life. Putting in place processes for effective collection of discarded products (e.g. extended producer responsibility in the electronics sector) will enhance circularity alongside innovative recycling technologies. Along this line, urban mining provides the opportunity to retrieve important materials from waste streams and helps reduce emissions and other environmental impacts of traditional mining.[204] For example, there is generally 100 times more gold in a ton of mobile phones than in an equivalent amount of gold ore, and 7% of the world's gold is locked up in e-waste.[205] An estimated US$57 billion worth of raw materials is potentially available in global e-waste as of 2019.[206]

Interventions must be supported by business models that promote the long-term use of products and sustainability. An example is the slow fashion concept, which encourages consumers to buy fewer clothes of better quality and durability, or the clothing-as-a-service model in which clothes and accessories are temporarily provided to customers through subscription or rental instead of owning them permanently.[207] In the electronics sector, electronics-as-a-service, device leasing, product take-back, return systems, reverse logistics and product-sharing systems are examples of business models that promote increased product life and durability and facilitate reuse, refurbishment, repair and recycling.[208]

Deploying these measures would lead to a circular supply chain in which manufacturers, sellers and users of products collaborate to ensure that the utility of products (textiles, electronics and other products discussed in other interventions) is extended and that discarded materials are recovered to make new products. Digital technologies such as sharing platforms, artificial intelligence and blockchain technology[209] (where applicable) will support achieving these objectives by improving logistics between product development, sale and eventual return to manufacturers. Promoting circular actions in product supply chains presents an opportunity for substantial climate action mainstreaming efforts.

Moreover, because of interconnected supply chains, one actor's efforts within the supply chain can help catalyse actions by others and lead to transformative change.

Substantial climate benefits can be generated from these interventions. For instance, textiles from recycled materials have lower emissions, and a business model that promotes the extended use and recycling of clothes can lower emissions by 44%.[210] Climate benefits will also accrue from recycling in the electronics sector.[211] The collection and recycling of just over 100,000 tons of e-waste containing chlorofluorocarbons and hydrochlorofluorocarbons in the Netherlands in 2017 led to the avoidance of about 0.4 million tCO_2e, which compares to the annual emissions of 119,000 gasoline cars in the country.[212]

Other environmental benefits across the textiles sector and the electrical and electronic sector include reduced use and release of toxic chemicals, including persistent organic pollutants and mercury, and decreased pollution and pressure on water resources. Others include reduced land contamination and forest degradation, less pressure on landfills or need to incinerate waste, reduced biodiversity loss due to mining and cotton farming, and better resource-use efficiency. Implementing circular solutions in supply chains will also create jobs and improve people's welfare, leading to better human health outcomes and promoting innovation.[213]

CASE STUDY 13: E-WASTE REPAIR, REFURBISHMENT AND RECYCLING FACILITY IN RWANDA[214]

E-waste management is a major challenge in many developing countries, often due to awareness, inadequate legislation, and limited financial resources. E-waste is predominately disposed of through open dumping, burning and landfills, with health and environmental consequences due to hazardous contents.

In Rwanda, the Government initially stored e-waste comprising discarded mobile phones, computers, stereos, light bulbs, televisions, refrigerators, washing machines and air-conditioners in warehouses, which was expensive and unsustainable. To solve this problem, a policy providing guiding principles for dealing with e-waste and relevant stakeholders' roles and responsibilities was developed. Building on this, a legal instrument comprising an e-waste law and regulations was enacted, followed by the development of e-waste recycling facilities that can process up to 10,000 tons of waste per year. The facility is managed through a public-private partnership between the Government of Rwanda and Enviroserve Rwanda Green Park, a private company.

Enviroserve Rwanda Green Park now operates e-waste collection points where the public drops off unwanted electrical and electronic goods, and collection services for large organizations and companies in Burundi, the Democratic Republic of the Congo, Rwanda and Uganda. At the facilities, e-waste is separated, repaired, refurbished and sold at discounted prices or donated. Much is dismantled, valuable materials are recovered, and hazardous materials are disposed of responsibly.

Although this is a relatively nascent initiative, more than 5,000 refurbished computers have been sold or donated since its inception, and upward of 4,000 tons of e-waste have been processed. Plastics and metals from the e-waste are crushed and recycled into chairs or construction materials, while electronic circuit boards are exported to an affiliate in Dubai, where precious metals like gold, silver, platinum and rare earth elements are recovered for reuse. The company is now aiming to expand to become the first lithium battery recycling facility in Africa.

Climate mitigation benefits so far from the facility are estimated at more than 2,000 tCO_2e. Apart from the climate and environmental benefits, the facility contributes to Rwanda's economy, including more than 600 jobs at the facility and more than 1,000 jobs at collection centres. The effort is also providing internship opportunities for students.

Intervention 14. Incorporating eco-innovation in industrial clusters, small businesses and informal networks

The success of many of the interventions discussed above will depend significantly on industries, economic sectors, and supply chains collaborating to promote resource-use efficiency and to reduce waste in the manufacturing and use of products. Circular measures promoting collaboration include business models that help create greater value and align incentives built on interactions between products and services – such as peer-to-peer sharing between businesses – to maximize the efficiency of capital goods.[215] The chemical leasing business model, in which chemicals are offered as a service based on their function and performance rather than focusing on selling large volumes,[216] is another example that encourages manufacturers to enhance the overall environmental performance of products.[217]

An effective way of promoting the circular economy across industries is to develop eco-industrial parks. Such parks are communities of businesses located on a shared property, seeking enhanced environmental, economic and social performance through cooperation in efficiently managing resources, promoting cleaner production activities and minimizing waste.[218] This type of collaboration is not limited to large industrial enterprises but also applies to micro, small to medium, and informal enterprises and has been deployed, for example, in India[219] and Kenya.[220] Urban symbiosis, which links waste in urban areas with industrial applications and vice versa, to create a symbiotic relationship that improves cities' overall eco-efficiency, has also been trialled, for example, in Japan, the Republic of Korea and Sweden.[221]

Digital technologies may be incorporated into this intervention to ensure an effective and transparent exchange of resources. Examples include platforms for leasing capital goods[222] and databases such as Tool SymbioSys[223] for companies to identify opportunities for material substitution and exchange.

The combination of resource efficiency and clean production leads to GHG emission reductions, improves efficiency in water and land use, and minimizes chemical and air pollution. The Ulsan Mipo and Onsan industrial park was reported to reduce carbon dioxide emissions by about 670,000 tons in 2015–2016, while also cutting air pollutant releases (SO_x and NO_x) by about 4,000 tons and promoting the reuse of approximately 79,000 tons of water.[224] Besides these benefits, business collaboration also provides overarching resource-use efficiency, creates jobs, promotes innovation and enhances relations with local communities.

CASE STUDY 14: THE WESTERN CAPE INDUSTRIAL SYMBIOSIS PROGRAMME IN SOUTH AFRICA[225]

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The Western Cape Industrial Symbiosis Programme (WISP), Africa's first industrial symbiosis programme, was developed to stimulate the economy in the Western Cape Province of South Africa, create jobs and reduce environmental degradation. About 6,000 tons of waste is generated daily in Cape Town, with 87% ending up in landfills, resulting in financial pressure to maintain existing landfills and commission new sites.

Funded by the Government and implemented by GreenCape, a non-profit organization, WISP provides a free facilitation service to create mutually beneficial links or synergies between member companies. It helps companies identify and realize opportunities to utilize unused or residual resources, by-products, and wastes from other organizations (materials, energy, water, assets, logistics and expertise), through data gathering and analysis, technical expertise, capacity-building and facilitated business introductory services. Major industrial sectors that are part of the programme include food and beverages, clothing and textiles, construction and demolition, metals and engineering (including electronics), chemicals and pharmaceuticals, and wood and wood products. The creation of the programme was facilitated by five policy levers:

- Development of road maps and strategies, including a green economy strategy framework
- Convening of multi-stakeholder partnerships from government, civil society and industry
- Awareness-raising and capacity-building
- Provision of adequate financial support
- Demonstration through a pilot industrial symbiosis programme

Examples of synergies achieved through WISP include:

- The exchange of plastics from a recycling company to a plastic crate manufacturer
- Transfer of waste egg whites from an ice cream manufacturer to a confectionary company for the manufacture of sweets at a lower cost
- Conversion of textile waste from a garment manufacturer to carpet underfelt by a material handling company
- Reuse of 4,500 m^3 of old concrete rubble as construction materials for a distribution centre
- Dismantling and recovery of components (metals, plastics and electronic parts) from end-of-life electronic equipment and sales of components to interested parties

Since its inception, WISP has generated significant climate, environmental and socioeconomic benefits. The emission of 147,700 tCO_2e has been avoided (equivalent to the yearly electricity consumption of more than 83,000 South African households). More than 104,900 tons of waste have been diverted from landfills. Sixty-four permanent jobs and 25 temporary jobs have been created directly, as have more than 200 indirect jobs. Every rand invested in WISP has been returned sevenfold in economic benefits. Over 120 million rand (US$8 million) in additional revenue, cost savings and private investment has been generated through the initiative. WISP's success has catalysed similar programmes across South Africa and other African countries, including Ghana and Mauritius.

ANNEX 2: GLOSSARY OF TERMS

Agroecology: Uses understanding of the interactions of important biophysical, technical and socioeconomic components of farming systems to design and manage agricultural production in a productive way while not damaging nature's goods and services.

Agroforestry: An ecologically based, natural resource management system, in which woody perennials (trees, shrubs, palms, bamboos, etc.) are integrated into farms and agricultural landscapes to increase diversity and sustain production. It increases social, economic and environmental benefits by enhancing food supply, income and ecosystem health.

Anaerobic digestion: The breaking down of organic matter such as animal or food waste, in the absence of oxygen, to produce biogas and biofertilizer.

Bendable concrete: A type of engineered cementitious composite in which the brittle nature of conventional concrete has been altered to produce a product with flexible and ductile properties.

Bio-based materials: Substances derived mainly from living matter or biomass.

Biochar: A charcoal-like substance produced through controlled biomass pyrolysis (burning in the absence of oxygen). Its properties make it a useful soil ameliorant that can sequestrate carbon and improve soil health.

Bioeconomy: An economic activity predominantly based on the use of biomass and biotechnology in the production of goods, services or energy.

Blockchain: A type of database that is replicated over a peer-to-peer network and allows multiple users in the network to access, share, maintain and update the content of the database in real time, safely and securely, according to an agreed consensus mechanism and without the need for a trusted central authority.

Carbon intensity: the amount of greenhouse gas emissions per unit of product (in kilograms of carbon dioxide per kilogram of product).[226]

Chemical leasing business model: A performance-as-a-product business model deployed in the chemical sector in which consumers buy the function and performance (service rendered) of a chemical instead of the chemical itself. This model encourages suppliers to focus on the function of chemical products rather than the volume or quantities they can sell.

Clothing-as-a-service model: A circular economy business model in which clothes and accessories are temporarily provided to customers through subscription or rental instead of the customers owning them permanently.

Cross-laminated woods: Fabricated wood products made by gluing together layers of lumber. They are lightweight but strong, easy to install, with superior acoustic, fire, seismic and thermal performance, and have low environmental impacts.

Devise or equipment leasing: A circular economy compatible business model in which individuals or businesses rent equipment or electrical/electronic devices rather than purchasing them.

Eco-industrial park: An industrial park that promotes resource-use efficiency, reduces waste and pollution and enhances socioeconomic gains through the cooperation of businesses and surrounding communities.

Electronics-as-a-service model: A product-as-a-service model for electrical and electronic equipment or devices in which users pay for the product's performance rather than outright ownership. The manufacturer is therefore responsible for ensuring continuous performance and end-of-life management of the product.

Embodied or upfront emissions: The emissions that occur in the production of any good or service, or in the case of buildings, for the building's initial construction.

Enteric fermentation: A natural process in the digestive systems of ruminant animals, including cattle, sheep and goats, in which microbes in the digestive tract decompose food, generating methane (a potent greenhouse gas) as a by-product.

Extended producer responsibility (also referred to as product stewardship): A policy that places significant responsibility for the end-of-life management of products on producers. This aims to prevent waste and promote the return of materials to the manufacturing cycle at the products' end-of-life.

Food miles: The distance that a food item travels from the producer to the consumer. The more the food miles of a given food, the less it is sustainable and environmentally desirable.

Green chemistry: Seeks to ensure that the design, development and implementation of chemical products and processes protect and benefit the economy, people and the planet by finding creative and innovative ways to reduce waste, conserve energy and discover replacements for hazardous substances. In green chemistry, the definition of performance of chemical products changes from functions alone to functions and sustainability.[227]

Green roofs (also referred to as living roofs): Whole or part covering of building roofs with vegetation to provide benefits such as rainwater absorption, insulation, enhanced biodiversity, better aesthetics, temperature regulation and heat island effect regulation.

Herd management: Herd management practices include improving sanitary conditions, animal health, herd renewal, and diversification of animal species to improve productivity and decrease the carbon intensity of livestock production.

Industrial symbiosis: Interaction between industrial facilities in which waste or by-products from one facility are used as raw materials by another.

Integrated pest management and ecologically based integrated pest management: Integrated pest management is a sustainable approach that uses the ecological relationship between crops, pests and the environment as the basis for pest management strategies that combine biological, cultural, physical and chemical options to minimize socioeconomic and environmental risks caused by pests. Ecologically based integrated pest management uses the interactions between crops, pests and naturally occurring pest-control organisms as the basis for modifying cropping systems and managing the negative impacts of pests.

Life cycle thinking or perspective: As defined by the Life Cycle Initiative, a "way of thinking that includes the economic, environmental, and social consequences of a product or process over its entire life".[228]

Managed grazing: Balancing animal grazing on grassland to avoid overgrazing and undergrazing and their negative impacts on soil health and carbon retention. Livestock is grazed on land with high-quality grasses and legumes and then rotated to other lands to allow the previous land to rest and regrow. Managed grazing improves overall farm health and builds the productive capacity of the land.

Manure management: The manipulation of manure bedding and storage conditions to reduce greenhouse gas emissions.

Mobility-as-a-service: A product-as-a-service model for transportation in which users can plan, book and pay for multimodal transit, usually through a digital channel. The model encourages a shift from outright ownership of personal transport towards shared mobility.

Nationally determined contributions: Non-binding national plans describing the climate actions, including policies and measures, as well as targets for greenhouse gas emission reductions, that governments aim to implement in response to climate change and as a contribution towards achieving the Paris climate agreement.

Nature-based solutions: As defined by the International Union for Conservation of Nature, "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits".[229]

Nitrogen-fixing crops: Instead of depending on the addition of nitrogen to soils for their growth, nitrogen-fixing crops pull nitrogen from the air with the support of common bacteria and then store the nitrogen in their roots. The subsequent release of nitrogen into the soil improves its quality. Examples of nitrogen-fixing crops include clover, soybeans, fava beans, garden peas, green beans, alfalfa, lupins, peanuts and rooibos.

Operational emissions: Emissions associated with the use of a product or service over its lifespan.

Organic agriculture: As defined by the Food and Agriculture Organization of the United Nations, "a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity by emphasizing the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfill any specific function within the system".[230]

Passive design: For buildings, involves reducing their energy consumption through design and architecture by carefully considering and optimizing building interaction with the local microclimate. This may include building orientation; windows and daylighting; flexibility in size, layout and functionality; and natural ventilation.

Permaculture: A holistic, nature-based agricultural system designed by considering the diversity, stability and resilience of natural ecosystems. It involves the harmonious integration of the landscape with people such that food, energy, shelter, and other material and non-material needs are provided sustainably.

Planned obsolescence (also referred to as built-in obsolescence): A business strategy in which products are deliberately designed to have a more limited useful life than possible so that they become out of date after a predetermined period.

Product-as-a-service model: A business model in which consumers purchase a desired result or function instead of the products (e.g. equipment, electronics, chemicals, textiles) that deliver the output or function. For example, instead of a company purchasing a photocopier, it buys a specific number of photocopies, while the manufacturer or supplier is responsible for the maintenance and end-of-life management of the photocopying machine.

Product take-back: The collection of used products or materials from consumers to be repaired, remanufactured or reintroduced into the original production process and manufacturing cycle.

Regenerative agriculture: A nature-based farming system that deploys practices such as cover crops, crop rotation and minimal tillage to reduce impacts from agriculture. It also incorporates techniques such as in-farm fertility management (using compost and green manure instead of synthetic fertilizers), improved crop varieties (e.g. nitrogen-fixing crops), agroecology, agroforestry, permaculture, organic agriculture, biochar addition and ecologically based integrated pest management.

Reverse logistics: The opposite of the traditional supply chain, which involves moving products inward (or travelling backward), aimed at capturing value, reuse of products and materials, or proper end-of-life management.

Selective breeding: In livestock management, selective breeding prioritizes the production of breeds with higher productivity or reduced emissions from enteric fermentation.

Sharing economy: An economic system based on the sharing of resources rather than outright ownership, usually facilitated by a community-based online platform.

Sustainable diets: Diets with low environmental impacts that contribute to food and nutrition security and healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair, affordable, nutritionally adequate, safe and healthy, while optimizing natural and human resources.[231]

Systems thinking approach: Examines the relationships between the different parts of a system, such as the product manufacturing and supply chains. It focuses on cause and effect relationships, and positive and negative feedback mechanisms, between the biophysical and socioeconomic features of the system. It also considers the interactions between components of a system across different locations and organizational levels and over time. Because many of these relationships are non-linear, understanding the connections between variables helps identify effective intervention points.[232]

Urban agroforestry: Practising agroforestry in and around urban areas. See agroforestry.

Urban and peri-urban agriculture: Agricultural activities – the cultivation of crops, herbs, and medicinal and ornamental plants; the raising of livestock and fisheries; and the growing of trees – within or around urban areas.

Urban mining: Recovering the stockpile of valuable materials from spent products, buildings and waste in urban areas. Urban mining recognizes that cities are the primary consumers of materials and emphasizes the potential of urban areas as a source of secondary raw materials for production.

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