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TRAINING MANUAL
TECHNOLOGY FOR CIRCULAR ECONOMY

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Table of Contents

Preface

The unsustainable use of natural resources is fueling multiple planetary crises: resource scarcity, pollution, climate change, and biodiversity loss. More than 100 billion tonnes of materials are consumed in our linear-based systems every year – a little less than the estimated weight of Mount Everest. Only 10 per cent of these materials are cycled back into the global economy. Approximately half of all global greenhouse gas emissions occur during the extraction and use of natural resources, such as minerals, metals and biomass. Each year, 5 trillion single-use plastic bags are discarded after a single use, choking our oceans and landfills.

The transition from a linear to a circular economy is more critical than ever to transform how we produce and consume and reduce our impact on the planet. An intentional and thoughtful transformation can also help to meet the UN sustainable development goals. Technology and innovation have vital roles to play in accelerating this transition, as demonstrated by the many cases in this Manual. To promote a circular economy, we must innovate in all arenas of the global economy: including material science, engineering, energy recovery and storage solutions, digital technologies, and business models. Universities will play a central role in educating, developing, and scaling solutions. They can further advance this cause by establishing broad collaborations with established industry stakeholders and technology firms. To realize a truly circular economy, we must reimagine critical infrastructure to be more modular and reusable and fit-for-purpose. There are opportunities in every critical infrastructure sector (water, sanitation, energy, waste management, and digital communications) to increase circular solutions in planning, development, and operations, while continuing to deliver uninterrupted essential services. The necessity of a sustainable infrastructure future, championed by UNEP and other global development partners, requires integrated planning, pragmatic financial support mechanisms, and robust governance structures to facilitate a truly circular transformation. Governments, businesses, and the investment sectors should dedicate significant time towards building an enabling environment, with regulatory conditions, project pipelines, and financial certainty, to unlock the opportunities that will help deliver circular innovations quickly and effectively. Regional and national programs like the EU SWITCH-Asia are fostering strong partnerships by providing insights, resources, and capacity building tools to incentivize actions throughout Asia. This is a model that could be adapted and replicated in other geographies, as needed.

The UNEP-Tongji Institute of Environment for Sustainable Development (IESD) is honored to contribute to this important work through the development of this Manual and as the host of this year's Leadership Academy on Circular Economy. Moving forward, we will continue to work with key stakeholders – including policymakers, business leaders, the youth community at the national and international levels in the journey towards a circular economy.

Professor WU Jiang

Vice President, Tongji University
Dean, UNEP-Tongji Institute of Environment for Sustainable Development (IESD)

Abbreviations

AI	Artificial Intelligence
BAT	Best Available Technology
BEI	Building Energy Index
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization and Storage
CEA	Controlled Environment Agriculture
EEDI	Energy Efficiency Design Index
EEI	Energy Efficiency Indicator
EFI	Energy Efficiency Index
EIA	Environmental Impact Assessment
EMF	Ellen MacArthur Foundation
EOL	End-of-life
GHG	Greenhouse Gas
IEA	International Energy Agency
IMO	International Maritime Organization
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LCA	Lifecycle Assessment
MFA	Material Flow Analysis
Mtoe	Million Tonnes of Oil Equivalent
NDCs	National Determined Contributions
PM	Particulate Matter
RoHS	Restriction of Hazardous Substances in Electrical and Electronic Equipment
RPAC	Regional Policy Advocacy Component
SDGs	Sustainable Development Goals
SMEs	Small and Medium-sized Enterprises
STAN	Substance Flow Analysis
SUPs	Single-Use Plastics
VRPs	Value Retention Processes
WCS	Warehouse Control System
WFP	World Food Programme
WWTP	Waste Water Treatment Plant

Executive Summary

The Training Manual on Technology for Circular Economy is developed for the EU SWITCH-Asia 2021 Leadership Academy on Circular Economy, a flagship capacity building activity **under the SWITCH-Asia Programme, funded by the European Union. This Leadership Academy was organized by the Regional Policy Advocacy Component of the SWITCH-Asia in partnership with UNEP and Tongji University.** The Leadership Academy is an annual event aimed at influencing mindsets and inspiring actions of young professionals in Asia towards a low-carbon, resource-efficient and circular economy.

The 2021 edition of the Academy is themed on technology and innovation for circular economy. The Training Manual provides a practical analysis to explore the role of technology in advancing a circular economy with a timely compilation of circular technology applications and case studies across Asia. It also discusses the challenges and opportunities to drive a circular transformation in Asia as the region continues to industrialize and urbanize. Finally, the Manual highlights the need for creating enabling policy and institutional conditions to foster innovation and accelerate the uptake of circular technologies and business models in Asia.

Circular economy has emerged as an attractive model to challenge the current linear economic system that is based on unchecked resource extraction and unsustainable consumption and production patterns. For the Asia & Pacific region, where the strong economic growth is largely fuelled by high material footprint, the transition to a circular economy is essential for achieving the Sustainable Development Goal (SDG) 12 on Responsible Consumption and Production. Technological innovations, from advanced recycling and recovery technologies to digital-enabled sharing platforms, hold great potential for transforming the way we produce and consume, thus contributing to a resource-efficient and circular economy. Innovative digital technologies and solutions, for instance, can promote greater transparency and efficiency across supply chains, extend producers' responsibilities and enable smart circular designs, which empower consumers to choose from circular products, services and lifestyles. This Manual features technologies and innovative business solutions that are deployed at various business sectors and value chains (e.g, consumer goods, food and agriculture, building and construction, industrial processes) to minimize waste and emissions, reduce the use of primary resources, and shorten (and eventually close) as many linear and wasteful economic loops as possible. It also introduces good practices and real-life examples of circular system models and highlights an integrated approach to achieve the overall economic, social and environmental sustainability of complex infrastructure systems such as industrial clusters and large urban development projects.

Realizing a circular economy will require a concerted effort among policymakers, scientists and researchers, and the business community to incentivize investment and bolster the adoption of circular technologies and business models at scale. By setting circular design standards and regulations, providing incentives and setting targets to extend product and building lifetimes, and investing in future-proof circular infrastructure systems, governments can lay the foundation for unlocking massive investments needed to accelerate clean technology diffusion at scale. However, the mass deployment of disruptive technologies and the rapid decarbonization in energy-intensive sectors may bring uneven impacts to the people and communities, particularly in low-income and middle-income countries. Thus, special considerations in policy designs and targeted assistance programmes at national, regional and local levels, are required to address these challenges and ensure a transition that is just and inclusive for all.

In the context of post-pandemic stimulus, it is imperative for governments to consider policies aligned with circular principles in their recovery packages. These include:

- Adopting green fiscal measures to support circular business models by reducing taxes on reuse, repair, remanufacturing and recycling activities, and regenerative food production.
- Removing fiscal subsidies on fossil fuels and introducing market-based mechanisms to put a price on carbon externalities.
- Incorporating circularity criteria into sustainable public procurement schemes.
- Promoting integrated infrastructure planning for a circular economy.
- Fostering local value chains by supporting local businesses, particularly small and medium-sized enterprises (SMEs).

Unit 1: Introduction to Circular Economy and the Role of Technology

1.1 Context

Imagine you walk into a restaurant on a hot summer day and order a drink. The next moment you are handed over your favorite drink, with a plastic straw in it. This all sounds normal, until you start asking yourself: “Do I really need the straw? What is it made of? What happens to it after I finish the drink in 5 minutes?”.

For a long time, our economy has been built on a linear “take-make-dispose” model, one that has significant impacts on resource depletion, environmental degradation, human health as well as climate change. Responding to the planetary crisis, the concept of circular economy has emerged as an attractive alternative to the current linear model. As governments, businesses and individuals around the world begin to rethink the way we produce and consume, advances in technology will play a critical role in accelerating the transition towards a circular economy.

This Unit will briefly introduce the concept of circular economy and its guiding principles. It will also provide an overview on the key circular economy initiatives at international and regional levels, and discuss the role of technology in the circular economy.

1.2 Learning objectives

After completing this Unit, participants will be able to:

- Describe the key features and benefits of a circular economy in comparison to a linear economy;
- Explain the concept of circular economy using UNEP’s “9R” circularity framework;
- Explain how technology and innovation can play a role in each link of the circular economy.

1.3 What is circular economy?

Circular economy is an economic system aimed at retaining the value of products, materials and resources for as long as possible, thereby minimizing primary resource use, waste and emission (Oberle et al., IRP and UNEP 2019; Hass et al., 2020)[1-3].

As opposed to a linear, “take-make-dispose” model in which natural resources are extracted as raw materials for making products that are quickly thrown away after use, a circular economy seeks to close the loops of energy and material flows by employing strategies such as reuse, repair, refurbish, remanufacture and recycle. In short, a circular economy employs the industrial ecology law to promote resource efficiency and recycling rate in an economy (Zeng and Li 2021)[4].

The linear growth path, which depends on the extraction and consumption of finite resources, is inherently unsustainable. Circular economy redefines growth by decoupling economic activities from resource extraction and designing waste out of the system, thus reducing environmental degradation and improving society-wide well-being.

The Ellen MacArthur Foundation, a global influence on, and advocate for circular economy, defines three guiding principles of a circular economy[5]. These are:

- Design out waste and pollution
- Keep products and materials in use
- Regenerate natural systems

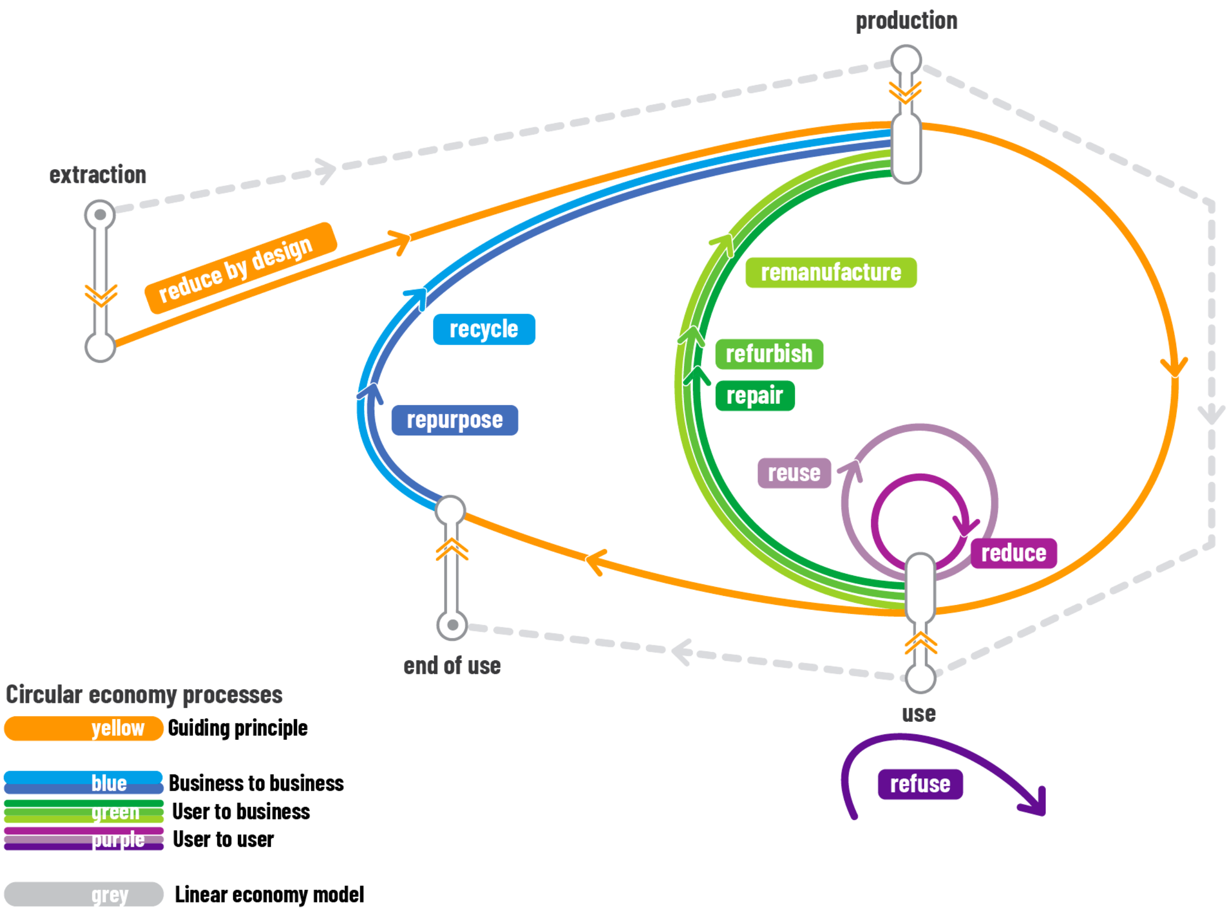
Key features and benefits of a circular economy, in comparison to a linear model, are outlined in **Table 1**.

Table 1: Comparison of a linear and a circular economy

Global challenges	A linear economy…	A circular economy…
Natural resource shortage	is resource-centric, therefore growth is constrained by the finite resource.	decouples economic growth from resource extraction and over-consumption.
Climate change & biodiversity loss	relies heavily on natural resource extraction and processing, which contributes to about half of global Greenhouse Gas (GHG) emissions and more than 90% of biodiversity loss and water stress (IRP 2019).	takes a restorative and regenerative approach to the use of natural resources, thereby reducing environmental impacts, including carbon emissions.
Inequality & well-being	exacerbates global inequality by generating waste and pollution, the burden of which falls disproportionally on poor and vulnerable populations.	minimizes waste and reduces pollution at source by designing externalities out of the system. As we transition to a circular economy, innovative business models could result in a net total of six million new jobs by 2030, compared to a business-as-usual scenario, according to an estimate by tne International Labour Organization (ILO)[6].

Understanding circularity: the “9-R” framework

The framework of circular economy is structured over the whole life cycle of goods and services across wider social and economic perspectives. A useful framework to understand and approach circularity is the UNEP “9-R” concept, as illustrated in **Figure 1**.



- *Figure 1: A Circularity approach*
Source: UNEP Circularity Platform[7]

The 9-R concept is built upon the following four "value retention loops", from the most impactful to the least:

- **From a whole system perspective: Reduce by Design**
  This is, reducing the amount of material used, particularly raw material, from the earliest stages of design of products and services. This should be applied as an overall guiding principle throughout value chains.
- **From a user-to-user perspective: Refuse, Reduce and Re-use**
  This includes, for instance, consumers saying no to certain products and services, and users choosing to buy less and/or second-hand or using products for a longer time. Consumer behavioral changes at this level can usually be implemented at little or no cost, while sending a strong signal to the market and businesses at the upper value chain to make necessary changes towards a circular economy.
- **From a user-to-business intermediary perspective: Repair, Refurbish and Remanufacture**
  This typically results in the extension of product lifetime, sometimes even a new (or as-new) service life for the product through comprehensive refurbishment or remanufacturing. Such Value Retention Processes (VRPs) between the user-to-business interface can significantly save costs and lower environmental impacts.
- **From business-to-business: Repurpose and Recycle**
  After a product reaches its End-of-life (EOL), manufacturers may adapt or reprocess the discarded

goods, in whole or in part, for another function. Recycling therefore provides a valuable source of material. However, it requires effective collection systems, technologies and infrastructures that are often lacking in many countries.

1.4 Towards circularity: where do we stand and what can we do?

Our world is only 8.6% circular, leaving a massive circularity gap[8, 9]. That means, for every 100 billion tonnes of materials we consume in our economy (a threshold that humankind has just crossed in 2020), only 8.6% is cycled back into the economy. However, if the circularity rate is doubled by 2032, we may not only close the gap of wasteful material consumption, but also return to a path towards a well below 2-degree world[10]. A circular economy also offers circular business opportunities that may yield up to US$4.5 trillion in economic benefits by 2030[8].

Global efforts to kick-start a circular economy are being rolled out at various levels.

In 2019, at the Fourth Session of the United Nations Environment Assembly (UNEA 4), the world's Ministers of the Environment agreed to "advance sustainable consumption and production patterns, including […] through circular economy and other sustainable economic models", and called for innovative solutions to achieve this vision.

The European Union has been a global champion for circular economy and put in place a comprehensive policy framework, including over 60 circularity strategies and roadmaps at regional, national and local levels[11]. The latest effort includes a new Circular Economy Action Plan aimed at accelerating the transformational change required by the European Green Deal.

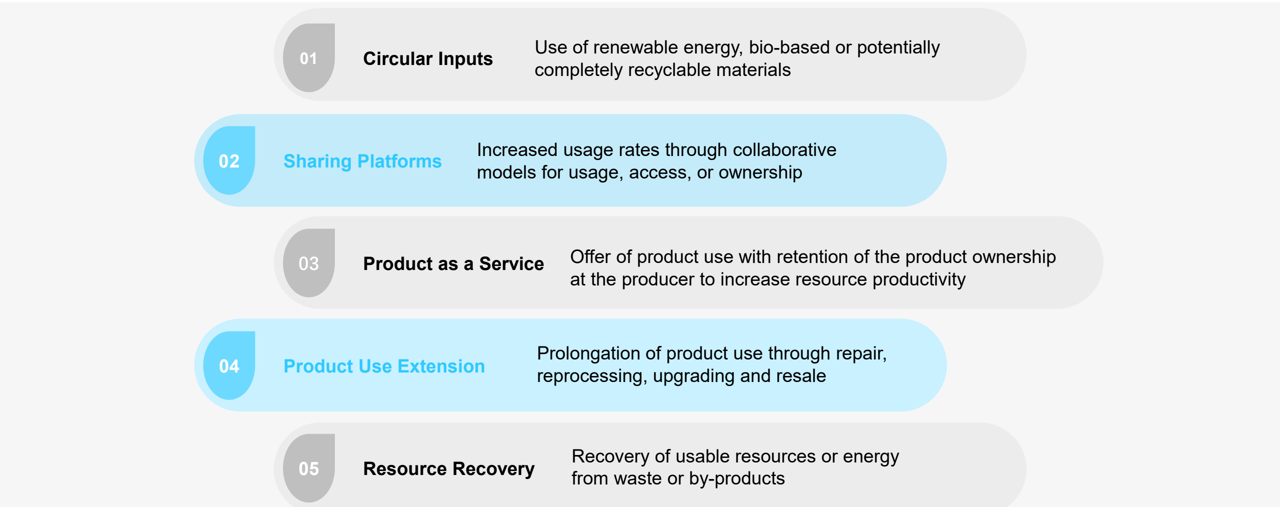
Circular economy is also gaining traction amongst emerging economies as a viable tool for realizing sustainable growth. In 2009, China adopted its national Circular Economy Promotion Law and spearheaded a national ban on waste imports in 2018, which shed light on the scale and urgency of ending the global flows of waste in the global trade network. India recently formulated a National Resource Efficiency Policy aimed at doubling the recycling rate of key materials in five years and mainstreaming resource efficiency across all sectors and regions of the country.

A global consensus on ending single-use plastic waste is forging. Many countries and cities have announced legislations and rules to ban single-use plastics. Rwanda, for instance, is aiming to become the world's first plastic free nation; since 2008, it has introduced bans on plastic bags and packaging[12]. In 2017, Kenya announced a nationwide ban on single-use plastic bags, and on World Environment Day in 2020, further tightened the ban on any single-use plastics in the country's protected areas[13].

Businesses are following suite. The New Plastic Economy, as per the Ellen MacArthur Foundation, will challenge a linear "thrown-away-after-first-use" business model, which currently leaves US$ 80-120 billion worth of plastic packaging material value out of the economy[14]. Through the New Plastic Global Commitment, more than 250 businesses across all stages of the plastic packaging value chain have pledged to eliminate plastic waste by 2025, representing more than 20% of all plastic packaging used globally[15].

More broadly speaking, by applying circular economy principles – that is, retaining the value of products and materials for as long as possible and eliminating waste – businesses will be able to reduce their dependence on finite resources, thereby saving cost, unlocking new circular opportunities to grow revenue and staying competitive. For instance, the size of a second-hand (resale) market is expected to grow from US$28 billion in 2019 to US$64 billion by 2024[16]. Another study suggests that by shifting the business model of internet routers from selling to renting out, manufacturers in Germany can reduce material loss by 80% and CO_2 emissions by 45%, compared with the linear business model[17].

Companies that are most successful at creating circular value seek to incorporate circular business modes with their value drivers through their operations, products and services. Here are five business models for driving a circular economy (**Figure 2**).



- *Figure 2: Five business modes for a circular economy*

Source: The Circular Economy Handbook[18]

Box 1: Innovative business practices for circularity

GreenBiz honored 20 C-suite sustainability champions for 2020, who are corporate leaders embracing the opportunity to lead their companies in sustainability long beyond the next quarter[19].

General Motors' corporate sustainable development goals include sourcing energy from renewable sources and obtaining at least half of the materials needed for automotive manufacturing from bio-based or renewable sources.

Stripe, an online payment processing platform, financed US$1 million for CO_2 capture and storage projects by launching an online platform where merchants can transfer a portion of each sale to carbon sequestration and show this to downstream shoppers at the time of purchase.

Natura & Co, a cosmetics producer, emphasizes the biologically diverse Amazon rainforest as the basis for their products, and a vital ecosystem to local dwellers. By collaborating with Natura in collecting natural forest products like Ucuuba berries, local residents receive better benefits than from felling trees.

Source: 20 C-suite sustainability champions for 2020 | Greenbiz

While governments and businesses are taking actions towards a circular economy, the ultimate driving force for change comes from each individual.

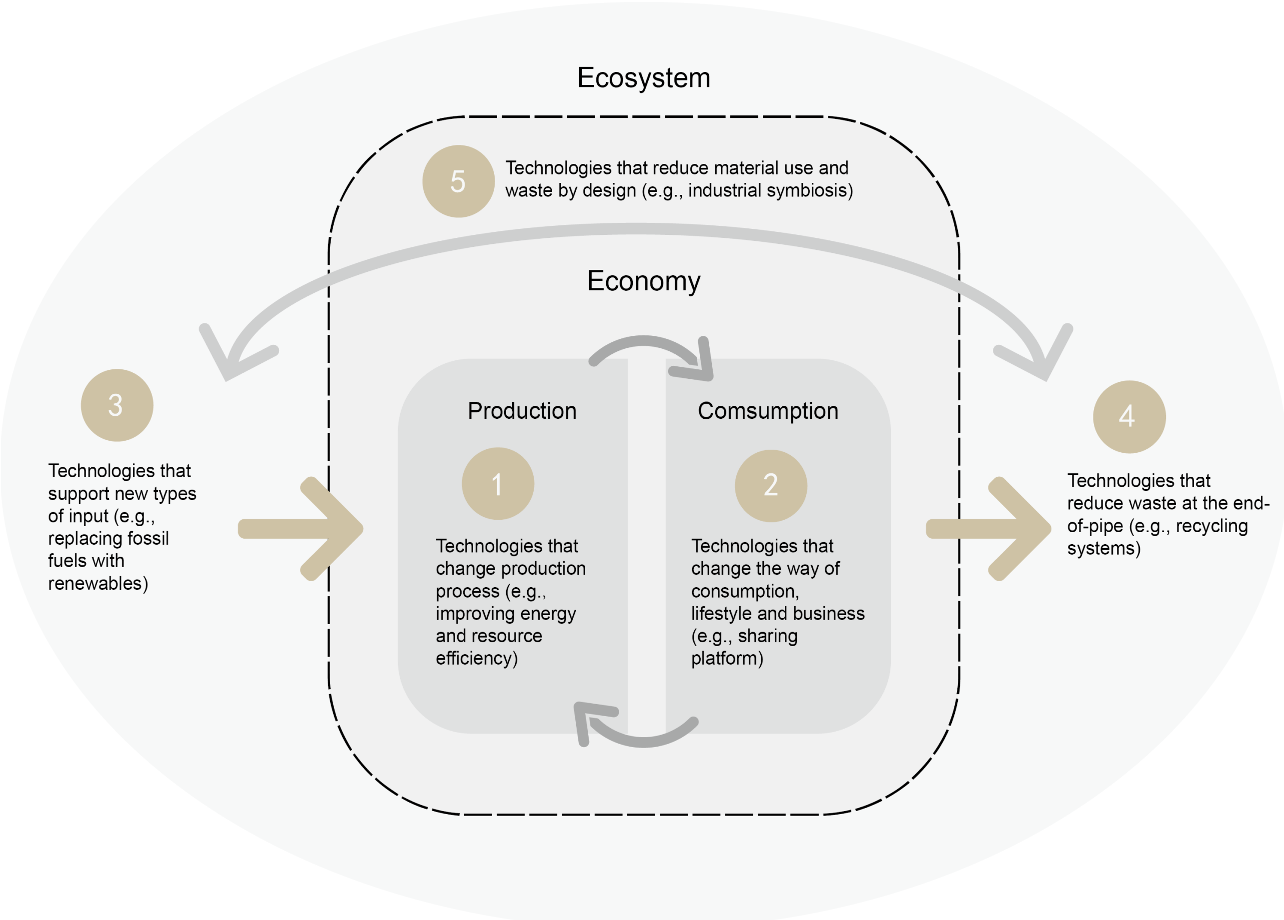
Each day, as consumers we collectively make millions of decisions: what to wear, where to eat, which packaging to choose. With each decision, comes a hidden price – one which is measured by its environmental footprint. Consider the example of the plastic straw mentioned at the beginning of this Unit. It takes months or even years to extract resources from the ground and convert them into a plastic straw that you only use to drink a can of coke for several minutes. Here is another timescale to consider: a plastic straw after use will stay in the environment for up to 200 years before it decomposes. By some estimates, there are nearly 7.5 million plastic straws laying around America's shorelines, and 437 million to 8.3 billion plastic straws around the world's coastlines[20]. The small act of saying no to plastic straws by every individual consumer could collectively be influential in preserving the planet.

Last but not least, responsible consumer decisions will not be possible without greater transparency across the value chain and reliable product/service information based on life cycle assessments. Governments, research institutes and NGOs are working to promote knowledge sharing and useful tools, including eco-labels, industry/corporate/product certifications, to empower customers in making the right decision. For example, Certified B Corporations are business that meet the highest standards of verified social and environmental performance, public transparency, and legal accountability to balance profit and purpose. B Corp Certification is one of the leading certifications that measure a company's social and environmental performance. The five assessment indicators of a qualified B Corp are: Environment, Workers, Customers, Community, and Governance[21].

1.5 Technology matters

Technology has played a vital role in achieving economic and social prosperity. However, the increased productivity and the over-exploitation and over-consumption of resources that come with technological advancements, have led to some unfavorable environmental outcomes, such as resource scarcity, habitat loss and environmental pollution, which put long-term sustainable development at risk.

Technology can be considered as both a source and solution of today's environmental challenges. In the context of circular economy, technologies can improve the value retention of materials and products and reduce waste – this is the focus of this Manual. **Figure 3** shows how various types of green technologies can be integrated into economic processes to promote circularity.



- *Figure 3: Green technologies for a circular economy*
Source: Inclusive Green Economy, Chapter 4 Green Technology[22]

Technology designed for enhancing circularity holds the potential to resolve sustainability challenges. Here is why:

First, technology could promote the decoupling of economic growth from resource use. Examples include technologies that improve the resource efficiencies of material, energy, water and land use, and innovations in material science, particularly more durable, environmental-friendly (i.e., biodegradable and renewable) alternative input materials. Unit 2 will further elaborate the role of technology in this aspect.

Second, technology – particularly digital innovations – can disrupt existing linear value chains and promote the decoupling of economic growth from over-consumption. Disruptive technologies, such as mobile technologies, big data analytics, cloud solutions, can open up new ways to connect and empower consumers to embrace circular options, as well as unlock new opportunities for circular business models. In the sharing economy, for example, the service precision and good user experience of a sharing platform rely on massive amounts of data processing and analysis, which is afforded by technology. Unit 3 will focus on the enabling role of technology in promoting sustainable consumption and production.

Lastly, technology – when applied at scale – can enable a systemic transition to a circular economy. Green solutions that integrate system-thinking, such as industrial symbiosis and nature-based solutions, can create great synergies across different sectors and value chains, in both technical and natural systems. This requires a shift in mindset which views the whole as larger than each part combined – an integral concept of the circular economy. Unit 4 will introduce some good practices and real-life examples of systemic circular models that are replicable in the Asia-Pacific region.

While the circular technologies and business models present important opportunities, it is imperative to put in place an enabling policy and investment framework to support the uptake of technological innovation. Unit 5 will discuss some policy considerations, especially in the context of COVID-19 green recovery.

One final consideration on the role of technology for circular economy is the effect of “circular economy rebound”. As argued by scholars, circular economy activities as a result of efficiency and technology improvement may increase overall production, which can partially or fully offset the environmental benefits that a circular economy is expected to bring (Zink and Geyer 2017)[23]. An analogy can be drawn with respect to the “energy efficiency rebound”, which occurs when increases of energy efficiency at the user-level are offset by the aggregated increase of total demand due in part to a lower unit price. Similarly, circular economy rebound is likely to occur when increases of material and energy efficiency at the production or consumption levels are offset by an aggregated increase of material and energy demand through price signals.

Increased use of refillable bottles, for instance, could lead to increased production and operation of refilling stations. Consumers, with increased awareness of recycling activities and technologies, might end up purchasing more disposable products, with the notion that they can erase the environmental impact of their purchase at the recycling bin.

To avoid the “circular economy rebound” effect, three measures are proposed (Zink and Geyer 2017)[23]. Firstly, it is necessary that circular economy activities promote products and services that truly are substitutes to the primary production. Secondly, circular economy activities shall seek to have no effect or a lower aggregated demand for goods and services. This is to say that they shall either target areas with fairly satiable demand (i.e., markets where buyers’ price sensitivity is low), or they must ensure that increased secondary production does not significantly affect overall prices. Thirdly, provided that the first two conditions are met, it is also necessary to ensure that circular economy activities actually draw consumers away from primary production.

1.6 Exercise

(1) Describe how a linear economic model operates.

(2) Compare and contrast the linear and circular economic models in relation to their impacts on resource extraction, consumption and waste generation.

(3) Using examples, explain how a circular economic model may be more sustainable than a linear economic model.

(4) The UNEP 9-R circularity framework outlines nine value retention loops. Pick one and discuss how it allows value to be retained (extended, recovered).

(5) Using examples, explain why some value retention processes are more impactful than others.

a) Based on the framework introduced in this section, identify the possible challenges in the transition to a circular economy.

b) How can technology and innovation help address these challenges and create new opportunities for circular business? Discuss using examples:

- Circular inputs
  Renewable energy, material innovation
- The efficiency of resource use
  Sharing economy
- Product as a service
  Long-term relationships with consumers as better services based on valuable data reflecting user's behavior and preferences
- Efficient maintaining of products or assets
  Efficient repairing plan, easy access to repairing services
- Resource recovery
  Promote engagement in the recycle process of a produce since the producer knows best their products and easiest for the producer to track and bring back the material into a value chain

1.7 Learning materials

Watch a 3-minute video: Explaining the circular economy and how society can re-think progress
https://www.youtube.com/watch?v=zCRKvDyyHmI&t=99s

UNEP Circularity Platform
https://buildingcircularity.org/

The Circular Economy in Detail, Ellen MacArthur Foundation
https://www.ellenmacarthurfoundation.org/explore/the-circular-economy-in-detail

The benefits of a circular economy for effective climate action and society, Potocnik and Okatz. GGKP 2021
https://www.greengrowthknowledge.org/blog/benefits-circular-economy-effective-climate-action-and-society

The circular economy: A paradigm shift for global solutions, Albaladejo et. al., Industrial Analytics Platform, UNIDO 2021
https://iap.unido.org/articles/circular-economy-paradigm-shift-global-solutions

Circularity Gap Report 2021
https://www.circularity-gap.world/2021

A New Circular Economy Action Plan – For a cleaner and more competitive Europe
EUR-Lex - 52020DC0098 - EN - EUR-Lex (europa.eu)

Circular business models archetypes, canvases, categories, elements, frameworks and strategies
De Angelis R. Business models in the circular economy: Concepts, examples and theory[M]. Springer, 2018. P55

The sharing economy is still growing, and businesses should take note, Forbes 2019
https://www.forbes.com/sites/forbeslacouncil/2019/03/04/the-sharing-economy-is-still-growing-and-businesses-should-take-note/?sh=4dde8e364c33

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Mathews, J. A.; Tan, H., Circular economy: Lessons from China, Nature 2016, 531, (7595), 440-442
https://www.greengrowthknowledge.org/sites/default/files/downloads/best-practices/Circular%20Economy%20(Lessons%20from%20China)_Nature.pdf

Unit 2: Technology for a Resource-efficient Circular Economy

2.1 Context

Natural resource depletion and environmental degradation point to the need for resource efficiency and decoupling economic growth from resource use and pollution. This Unit will focus on technological solutions and opportunities for improving resource efficiency and circularity in production systems and incorporating circular design and material innovation in business models.

2.2 Learning objectives

After completing this Unit, participants will be able to:

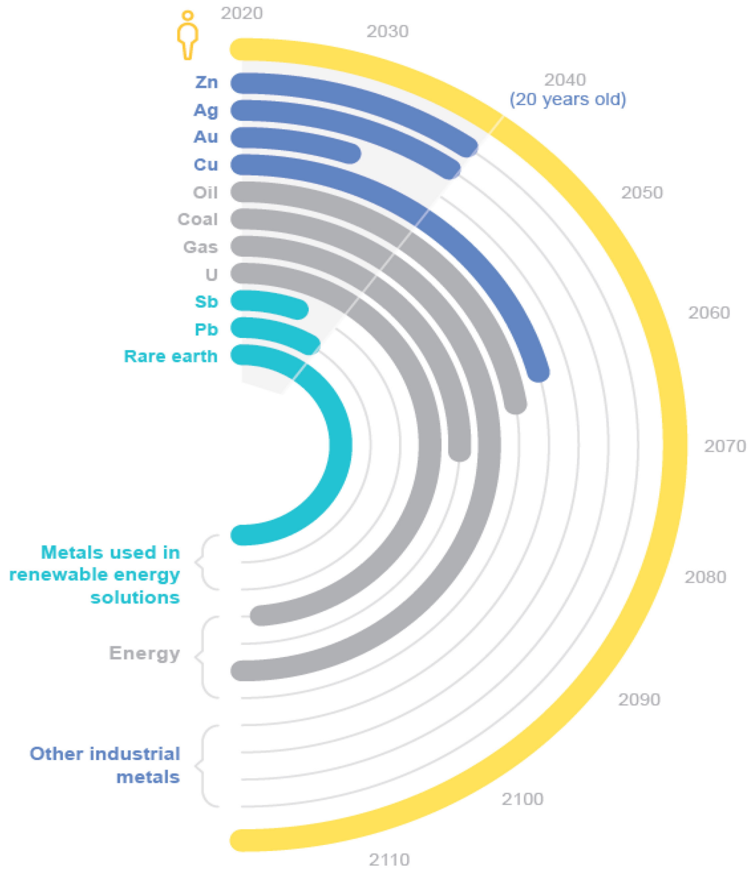
- Understand the key causes of natural resource depletion and the importance of promoting resource-efficient technologies in a circular economy;
- Identify at least 3 circular design strategies that can be applied to consumer products;
- Explain the role of technology in reducing primary material use, pollution and emissions at source through material innovation and improved recycling.

2.3 Resource efficiency: what's at stake?

Global material resource extraction has tripled over the last 50 years, reaching 100 billion tonnes in 2019 (IRP 2019; CGRi 2021)[2, 9]. The growing global demand for material use is driven in part by population growth and improved well-being, but also by unsustainable production and consumption patterns stemming from a linear, "take-make-dispose" economic model.

Such a model not only leads to new waste flows and unprecedented levels of pollution and GHG emissions, but also pushes planetary boundaries beyond their limits (IRP 2019)[2]. Furthermore, most of the material resources[*] we use today are non-renewable resources. At the rate of current material extraction and processing, the stock of natural resources will simply not be enough to meet increasing demand (Covestro 2021)[24]. According to the United States Geological Survey, metals such as zinc, gold, and silver – all of which are important for the production of electrical and electronic products – will be depleted in 20 years' time (**Figure 4**).

[*]Note: Material resources referred in this Manual are biomass (such as wood and crops for food and plant-based materials), fossil fuels (such as coal gas and oil), metals (such as iron, aluminium and copper) and non-metallic minerals (such as sand, grave and limestone) used in the economy.



• *Figure 4: Exhaustion date of natural resources*
Source: United States Geological Survey, Covestro Circular Design Guidebook, 2021[25]

To address issues of environmental degradation and natural resource shortage, it is imperative for countries to promote resource efficiency measures, which can help decouple economic growth from resource use and negative environmental impacts.

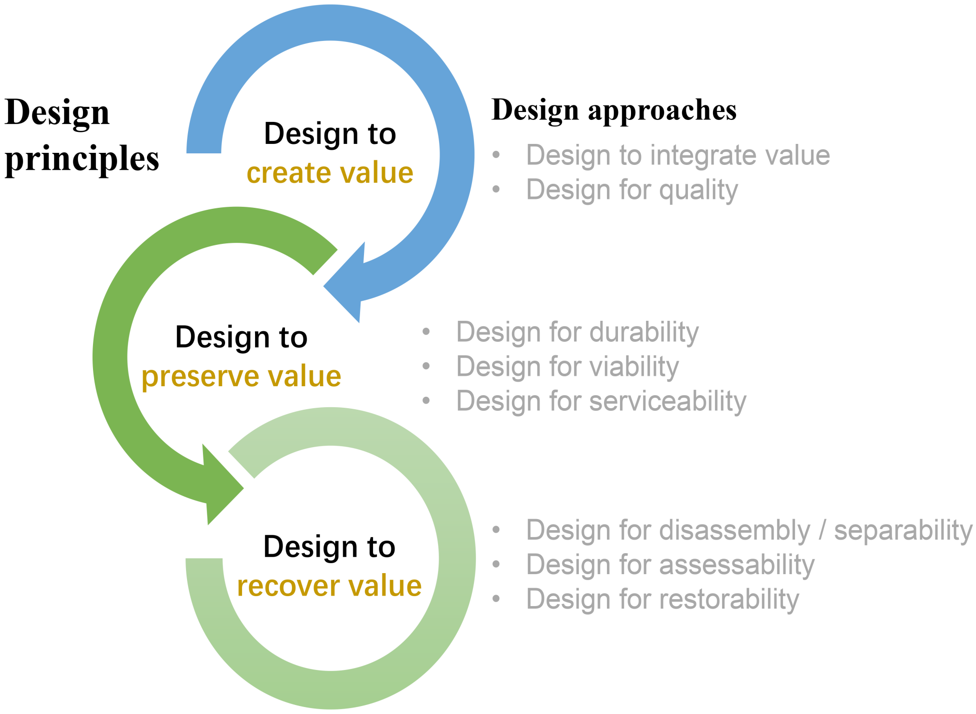
A resource-efficient economy means "doing better with less", or in technical terms, "achieving higher outputs with lower inputs" in the global production system (IRP 2019)[2]. Improvement and innovation in resource efficiency could contribute to de-materialization (reduced material use at source) and re-materialization (reduced material use through reuse, remanufacturing and recycling), which provide an important lever to the transition to a circular economy. The following sections in this Unit will explore existing or emerging technologies that can be applied to improve resource efficiency in the production system, as well as innovative business models and best practices that embrace the circular economy.

2.4 Design for circularity

Most things we use today (single-use plastic packaging, "fast-fashion" clothing that is no longer trendy the next season, smartphone accessories that are often not compatible between brands) are still designed for the linear model. A system-wide shift to embrace circular design thinking is required to improve the resource efficiency and circularity of our economy.

"Reduce by design" comes as the first circular approach in the UNEP "9-R" framework. From consumer products, to manufacturing processes, to even system-wide urban planning, the circular design approach should be applied as the guiding principle across value chains in order to reduce the material load/input at the earliest possible stage.

A circular design entails the key principle of maintaining the value of products, materials and resources for as long as possible. Common design approaches include designing to create, preserve and recover value from different value retention processes (**Figure 5**).



- *Figure 5: Circular design principles value retention processes*
Source: IRP (2018)[26]

The following **Table 2** summarizes five strategies for creating circular business models, in which technology (i.e., digital solutions) often plays an enabling role in the uptake of these models. Another useful toolkit, the "Circular Design Guide", developed by the Ellen MacArthur Foundation and IDEO, provides insights and business cases for designers and innovators who want to incorporate the principles of circular economy into their work.

Table 2: Five circular design strategies (Adapted from: Covestro Circular Design Guidebook, 2021)[24]

Circular Design Strategy	Key Features	Example
1. Dematerialization (Design for light-weighting)	A design strategy that uses as few materials as possible without compromising the functionality and utility of a product. Enabled by digital solutions, this could mean a total transformation from physical to virtual form.	**Online music streaming: Spotify** At its peak in 2000, traditional CD production in the US used 61,000 tonnes of plastic[27]. The digitization of music and the emergence of online music streaming platforms such as Spotify, however, have reduced CD production, and in turn, plastic use by 53,000 tonnes. It is noteworthy, however, that although streaming has reduced the amount of material and plastic production and waste involved in music delivery, it has significant environmental impacts in terms of carbon emissions related to storing and processing music online.
2. Product-as-a-Service (PaaS) (Design for serviceability & quality)	Reducing the need for consumers to permanently own products that will only be used for a short period of time, business models such as leasing, subscription offer consumers the product as a service. This allows businesses to focus on improving product durability and the quality of after-market servicing as their profitability no longer depends on the number of products sold. This strategy reduces the need for mass production and improves overall customer engagement and satisfaction.	**Philips' Lighting-as-a-Service of LED lamps[28]** LED light sources are highly energy efficient but remain expensive especially for large buildings. Since 2015, Philips has provided lighting as a service to Schiphol Airport in Amsterdam, by leasing LED lighting. In this model, Schiphol Airport pays for the LED lighting bills without having to pay large equipment costs upfront. Philips owns the LED lights and is responsible for their maintenance and proper recycling at the end of their service life.

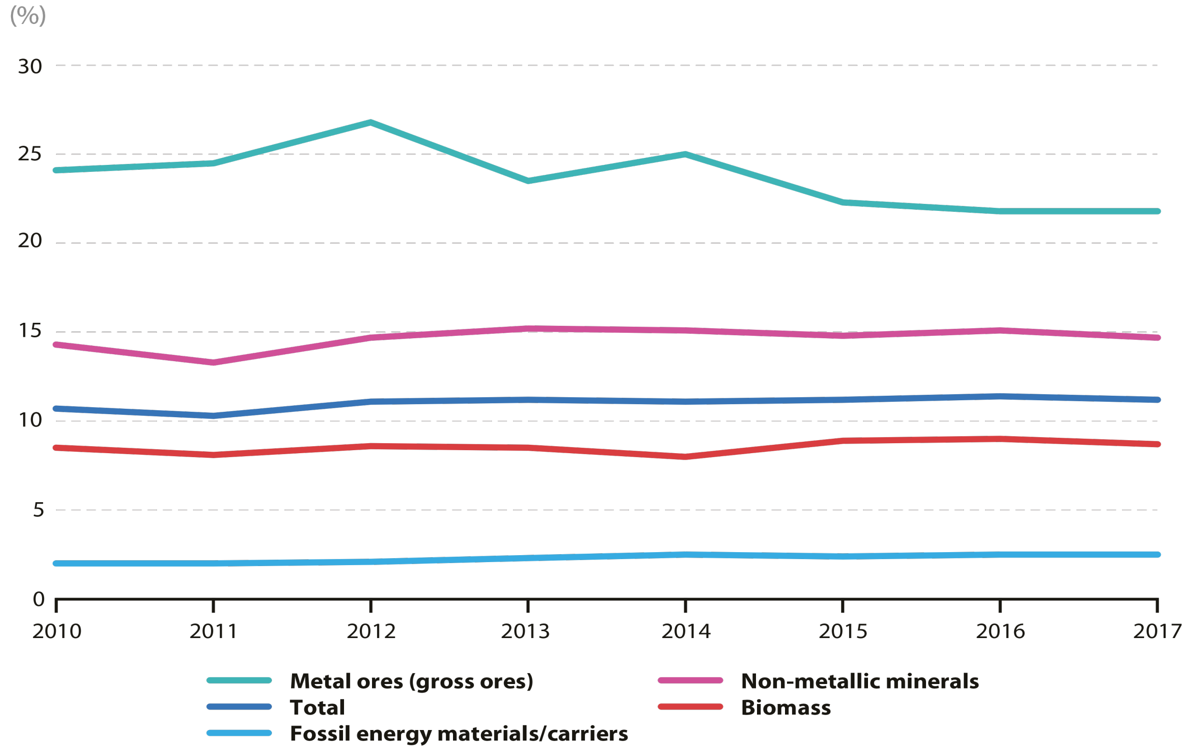
3. Design for extended product life (Design for quality, durability and restorability)	A design strategy to satisfy the changing needs of users over time by maximizing a product's value and prolonging its lifespan. This typically includes designing for physical durability, making the product and its individual parts maintainable, upgradable, easy to repair, remanufacture and refurbish. It can even allow for repurposing, reuse or reselling, which can increase the use-cycles of the product before it reaches its end of lifetime.	**SKF remanufactured bearings**[29] Remanufacturing means to rebuild a product to its original specification using a combination of reused, repaired and new parts.  SKF is a global manufacturer of bearings and seal products, who also remanufacture large-size bearings. This can extend the bearing service life by 50% while reducing costs by half as compared to producing a new bearing. Remanufacturing can also reduce CO_2 emissions by 80% as it involves less manufacturing processes than producing new products. *Source:* www.skf.com **Patagonia** Patagonia extends the lifespan of their products by designing them to be physically durable, reparable and high quality. The zippers on their products, for instance, are designed so that they can be repaired without removing the zipper's lining or losing any down fill. Their 'Worn Wear' initiative also allows customers to bring in their clothes for repair or trade in garments beyond repair to be repurposed or recycled. By keeping their products in circulation and in use for even just nine additional months, Patagonia can reduce the environmental footprint of their products by up to 30%.

4. Circular material choice (Design for quality, durability and recyclability)	A design strategy that favors materials which are harmless to the environment (e.g., renewable, biodegradable) and the human body (e.g., non-toxic), and easy to recycle, repair and refurbish during the product lifetime. This strategy keeps material resources in the value chain for as long as possible.	**Banana leaves as packaging**  In Chiang Mai, Thailand, Rimping supermarket has been using banana leaves instead of plastic as packaging material. This solution is less harmful to humans as well as the environment than plastic packaging as the leaves are chemical-free, they fall down naturally when bananas are picked and are fully biodegradable[30]. *Source: https://www.forbes.com/sites/trevornace/2019/03/25/thailand-supermarket-uses-banana-leaves-instead-of-plastic-packaging/*
5. Modular design (Design for disassembly and separability)	A modular design enables the removal of parts and the easy disassembly of a product after EOL. This reduces the cost and workload of replacing damaged parts. This strategy not only makes the product easy to upgrade, repair and remanufacture, but also offers flexibility to meet diverse market needs. The standardization of component specifications cross-brand or cross-product-line can also increase the utilization rate of parts in the overall market.	**The Modular design of Fairphone[31]**  Fairphone designs and produces smartphones with minimal environmental impact. Fairphone created one of the first modular smartphones, for instance, allowing for damaged screens to be quickly and cheaply replaced. The Fairphone is designed to be easily repaired and upgraded. The company not only sells spare parts, but also has a “take back program” which supports the reuse and recycling of used phones. *Source: www.fairphone.com*

2.5 Circular material use rate

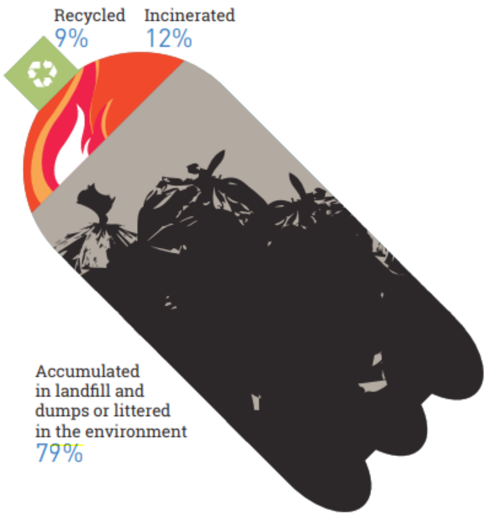
The circular material use rate, also known as the circularity rate, is defined as the ratio of circular use of material to overall material use in an economy[32]. The circular material use rate is an important indicator to provide insights on the overall circularity of a country's economy. A higher circular material use rate indicates that more secondary materials, instead of becoming waste, are effectively recycled to substitute for primary raw materials. This reduces the environmental impacts of extracting primary materials. This section will discuss how innovative technology solutions and processes can enhance both the quantity and the quality of secondary raw materials – plastic, building materials, metals, among others – to increase the circular material use rate and the overall circularity of an economy.

In 2017, the EU's circularity rate was 11.2%, meaning that for every 100 tons of material resources used, 11.2 tons came from recycled products and recovered materials (Eurostat 2020, **Figure 6**)[34]. By material group, metal ores had the highest circularity rate of 21.8%, followed by non-metallic minerals (including glass) at 14.7%. Fossil energy materials had the lowest circularity rate. This is partly due to the fact that fossil fuel materials are mostly used for energy and released as GHGs, thus are less suitable for recycling. However, the recycling of plastic materials, currently only at 9% worldwide, offers significant room for improvement (**Figure 7**).



- *Figure 6: Circular material use rate by material categories, EU-27, 2010-2017*
Source: Eurostat (online data code: env_ac_curm)[33]

The EU Circular Economy Action Plan 2020 sets out an ambitious target to double its circular material use rate in the coming decade. To achieve this goal, advanced recycling and material recovery technologies for plastics, construction and building materials, and metals (e-waste in particular), can help boost the circular material use rate.



- *Figure 7: The state of plastic recycling*

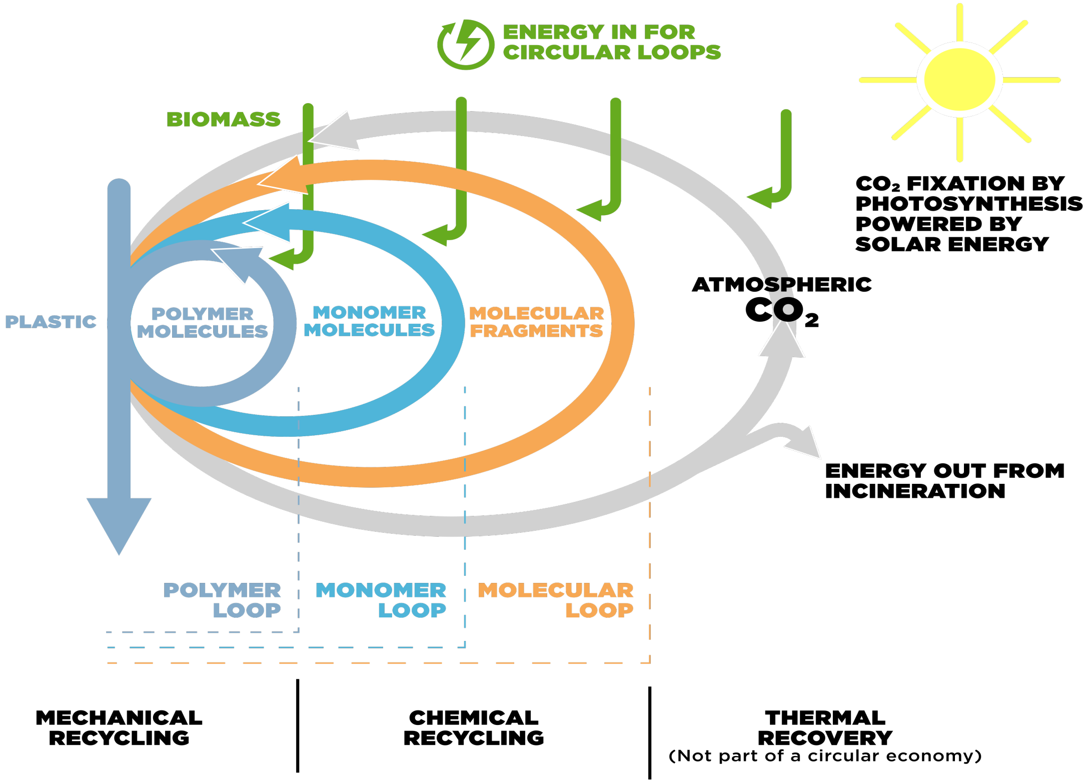
Source: Geyer, Jambeck, and Law, 2017 [35]; Jambeck et al., 2015[36]

For instance, Avient Corporation, a specialized and sustainable materials provider, has partnered with Oceanworks® to tackle the issue of ocean plastic waste[37]. The collaboration will launch and expand the use of recycled plastic formulations that can reduce the demand for new virgin plastic in a wide range of applications, from personal care products to office suppliers and footwear. The use of Oceanworks® Guaranteed recycled ocean plastic, will not only improve the source authenticity and traceability of the plastic supply chains, but also ensure social and environmental compliance, thereby encouraging the uptake of recycled content by consumer brands to meet sustainability commitments.

In the building sector, the use of recycled materials is increasingly made possible by technologies. The building of United States Environmental Protection Agency, which is made with 27% of recycled materials such as fly ash and gypsum wallboard, offers a prime example of a green building concept[38]. The demolition of the Grand Prince Hotel Akasaka in Tokyo is another example. Using a novel deconstruction technique, they were able to preserve building materials, generate energy and reduce the carbon emissions of the process by 85%[39].

In places where recycling infrastructure is relatively well established, mechanical recycling offers a good solution for many materials such as metals, glass and some plastics[40]. Yet, the Global E-waste Monitor (ITU 2020)[38] finds that only 17.4% of the world's 53.6 million tons of e-waste was recycled in 2019[41]. The rate is high in Europe (42.5%), however in many other regions such as Asia, for example, only 11.7% of e-waste is recycled. This is important as it is estimated that US$10 billion worth of raw materials could potentially be recovered from e-waste. Moreover, e-waste materials such as iron, aluminum and copper are important second-life raw materials, which can reduce the extraction of virgin raw materials and save up to 15Mt of CO_2 equivalent emissions from primary mining.

Innovation in the chemical industry is focusing on solutions that use recycled materials as a source of feedstock in chemical production without having to change current manufacturing processes. As shown in **Figure 8**, this type of chemical recycling is particularly useful in dealing with complex or mixed components, such as plastic products that often contain more than one component or contaminant, which would otherwise make them technically and economically inseparable through mechanical recycling.



- *Figure 8: A diagram of plastic recycling options***
  Source: EMF Mass balance approach White Paper[40]

Finally, a higher circularity rate requires an economy-wide transformation, beyond increasing recycling rate. This entails, for example, replacing fossil fuels with renewable energy, using more efficient production technologies and extending the lifespans of products.

2.6 Material innovation

Material is one of the fundamental building blocks to society and the modern economy. Technological innovations are constantly transforming the production and use of materials, by for instance developing new, eco-friendly, energy-saving and resource-efficient materials that reduce negative environmental impacts such as pollution and GHG emissions. In this section, we will explore some technology trends and good practices and discuss ways in which material innovation can contribute to a circular economy.

2.6.1 New materials could improve resource efficiency by replacing conventional materials that have higher carbon footprints

Advancements in material science have given rise to a range of high-performance materials, in particular nanomaterials. These have desirable qualities in terms of material performance; their light weight, strength

**Note: The composition of plastics determines which recycling loop option is technically and economically feasible or preferred. The more mixed and worn the plastic waste is, the more to the right the most-suited loop reaches.

and flexibility enable green and circular applications in the energy saving, green building and renewable energy production industries. Examples include super-insulating materials for temperature control, lighter and stronger materials for automobiles, efficient lighting devices, fuel cells (Serrano et al., 2009; Mao and Chen 2007)[42, 43] and nanostructured materials based photovoltaics (Varghese et al., 2009)[44, 45]. Moreover, with advancing Artificial Intelligence (AI), material scientists could even accelerate innovation processes by using the power of algorithms to analyze massive amounts of material data at scale and gain novel insights on material properties, before moving to the physical experiment stage for verification[46].

In the conventional built environment industry, innovation is also taking place to reduce the carbon footprint of concrete – the most widely used construction material in the world.

Box 2: Innovation in Low-carbon Cement and Concrete

A Chatham House report examined the key innovation trends in low-carbon cement and concrete. The making of cement, which is a key raw material for concrete, involves the calcination of limestone to produce clinker, which is highly energy-intensive and carbon-intensive and responsible for about 8% of global CO_2 emissions (Lehne and Preston 2018)[47].

At the same time, cement and concrete are expected to play a vital role in the fast expansion of infrastructure development and urbanization, particularly in the emerging economies of South and Southeast Asia. Many critical infrastructures providing, for instance, clean water, sanitation and clean energy, such as hydropower dams, typically rely on concrete. Thus, the cement and concrete sector face both the opportunity and challenge to curb emissions while keeping up with growing demand.

There are a number of low-carbon solutions to reduce emissions from cement production, including energy-efficiency, switching from fossil fuels to alternative fuels, and Carbon Capture and Storage (CCS) technologies. Furthermore, by introducing changes to cement composition, new material innovation offers a unique opportunity for decarbonization in the cement industry. This could also include developing alternative materials such as clinker substitution (a component that is responsible for more than 50% of cement sector emissions) and scaling up the deployment of “novel cements”, some of which can even absorb CO_2 to become carbon negative. For example, Solidia, a US-technology company, is partnering with major cement producer LafargeHolcim to produce a low-clinker-content CO_2-cured concrete that can reduce CO_2 emissions by 70%, compared to ordinary cement[48].

Source: Lehne, J., and Preston F., Making Concrete Change – Innovation in Low-carbon Cement and Concrete, Chatham House, the Royal Institute of International Affairs, 2018

Natural materials are eco-friendly and regenerative, and thus an ideal circular material to replace industrial construction materials. For instance, bamboo is a particularly attractive building material in developing countries as it is cheap, locally available and quick to grow. There is growing interest and development in the use of bamboo, for instance as flat panels for floor boards and walls, large laminated sections for use in external joinery, and concrete reinforcers providing structural support (Ghavami 2008)[49]. Bamboo has been found to outlast steel when used to reinforce concrete (Ghavami 2005)[50]. Bamboo is also flexible enough to create domes and other curve-shaped structures that may be difficult to build with other materials (INBAR 2010)[51].

Furthermore, compared to steel, little industrial processing is needed to cure and process bamboo. This reduces transportation and construction costs and can enhance job prospects for local construction workers who have no access to training or facilities for the production and use of manufactured construction materials (Ghavami 2008)[49].

Box 3: Bamboo-based building systems in India

The UK based Timber Research and Development Association designed a project in India to provide education on cost-effective bamboo-based building systems. The project aimed to demonstrate how bamboo can be used to make construction safe, secure, durable and affordable even to the poorest communities in India. It also sought to show that bamboo is as durable as other building materials.

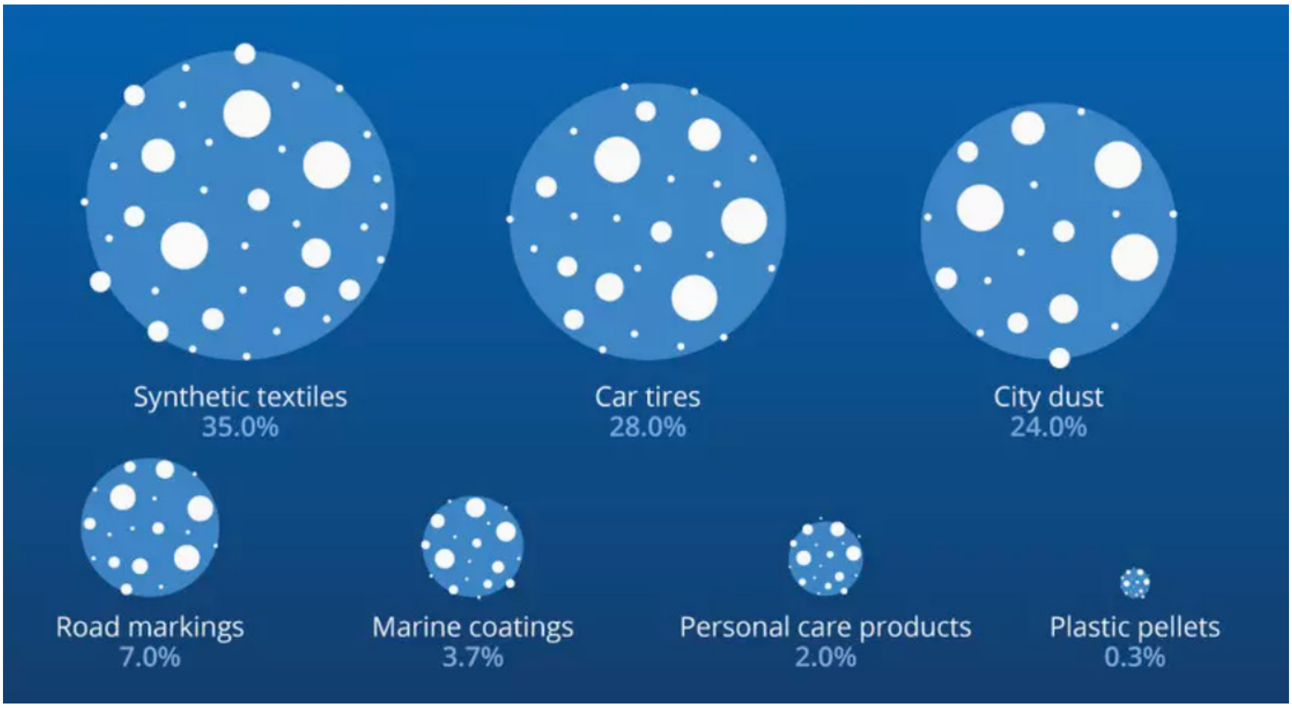
The building systems they designed were half the cost of traditional brick or reinforced concrete designs. They were simple to erect, easily adjustable, and incorporated all of the essential requirements for affordable shelter. At the same time, they were sustainable, resisted wind, earthquakes and other harsh environmental conditions. Using bamboo also helped improve the environment by protecting wildlife habitats, reducing erosion, and acting as a carbon sink. Bamboo cultivation and processing also supported the local economy by providing a food source, a local industry and jobs such as bamboo harvesting, processing and building (Jayanetti and Follet 2003)[52].

2.6.2 New materials could be less harmful to the environment and human health

Electronic products and their accessories are often made of toxic substances or made with processes involving using toxic chemicals, such as hexavalent chromium and lead.[53] Exposure to high concentrations of these toxins poses significant health threats to people. Hexavalent chromium, for example, is classified as a carcinogenic (Group 1) by the International Agency for Research on Cancer and may cause irritation to the human body. When released into the environment, toxic substances, particularly heavy metals, can accumulate in the biosphere and enter human food chains.

Considering these environmental and health-related threats, there are growing consumer pressures and global efforts to regulate and phase out the use of toxic substances in electronic products and their supply chains, and replace them with greener and safer materials. For instance, since 2003, the EU regulation on the Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS) has successfully reduced the use of toxic substances such as lead[54]. In 2019, Parties to the Minamata Convention on Mercury agreed to ban the manufacture, export and import of various mercury-containing products starting from 2020[54]. This will likely stimulate research and innovation in new, replacement materials.

Another material of concern is plastic. Versatile, cost-effective, lightweight and durable, plastic materials have become one of the most commonly used materials and plays a vital role in the modern economy. However, the sheer amount of plastics produced and disposed has overwhelmed earth's systems and resulted in a significant toll on the environment, the economy and society as a whole[55]. For instance, ocean plastics may break down into microplastics (small pieces of plastic less than 5 millimeter in diameter) and eventually enter into human food chains (Thompson 2016, **Figure 9**)[56, 57].



• *Figure 9: Distribution of Sources of Microplastics in the World's Oceans*
Source: International Union for Conservation of Nature (IUCN), Statista[57].

However, there have been global efforts to address these problems. Following the World Environment Day in 2018, a global resolution addressing single-use plastic pollution was adopted at the Fourth Session of the United Nations Environment Assembly (UNEA 4) in 2019[58]. It called for innovations in affordable and environmental friendly material alternatives to single-use plastic products. Furthermore, the increasing number of countries adopting single-use plastic bans presents opportunities for innovation in biodegradable plastics and bio-based materials, which can replace plastic food and e-commerce packaging, and agricultural film.

Box 4: Green biomass replaces plastic in food packaging

A new research project, named 'SinProPack', in Denmark is piloting a packaging solution which uses 100% biodegradable, locally sourced upcycled grass fibers to replace plastic take-away food packaging.

The grass is harvested and its protein is extracted for cattle feed. Next, the remaining fibers, which constitute around 70% of the grass, undergo a biorefining process. The grass fibers are then converted into cellulose, from which the food packaging is produced. Apart from grass, the researchers are also looking at clovers and other biomass harvested from peat soil as potential fiber sources.

The project is a collaboration between Aarhus University, the Danish Technological Institute, and LEAF Packaging, and has demonstrated the possibilities of using easily accessible, efficient, moldable high-yielding green biomass to replace single-use plastic packaging for food. Using the established green biorefining process for protein production, the Project exemplifies a sustainable bioeconomy business model, which uses technology to deliver environmental benefits[49].

Thanks to technology advancement and increased consumer awareness, bio-based food packaging as an alternative to single-use plastics has become an economically viable business model and realized commercial-scale success in many countries. In Thailand, EDEN Agri-Tech uses 100% edible natural coatings to help preserve and extend the life of fruits and vegetables up to three times. Founded in 2010, Ecoware has grown to be India's largest consumer brand for sustainable food packaging, offering affordable and biodegradable tableware products made from 100% common crop waste such as sugarcane and wheat[50].

Source:
https://www.eurekalert.org/pub_releases/2021-05/au-grp052521.php (Aarhus University, 2021)
https://ecoware.in/about/
https://www.edenagri.co.th/

2.7 Exercise

(1) Discuss 3 real-life examples of innovative materials and/or design concepts that hold the potential to transform our economy to a more circular one.

(2) a) Globally, only about 9% of plastic packaging materials are effectively recycled. More than 50% are disposed and 32% leaked into the environment. Why do you think that the recycling rate for plastic packaging is so low?

b) Identify the key barriers to effective recycling in the plastic value chain.

c) What are the circular strategies that businesses and consumers can apply to reduce, reuse and recycle plastic packaging materials? Discuss with concrete examples.

d) What are the potential challenges that these circular strategies could present?

(3) How much End-of-life (EOL) waste is recycled worldwide? How much of the world's material inputs are supplied by recycling?

(4) Explain in what ways a company can achieve a circular business mode?
(Eg: Efficient asset management, sustainable product design, use circular materials, circular supply chain…) Discuss the potential challenges of businesses adopting circular business models and suggest ways of addressing these challenges.

(5) Using examples, explain how resource efficiency and material innovation can contribute towards a circular economy.

2.8 Learning materials

Circular Design Guide, the Ellen MacArthur Foundation and IDEO
https://www.ellenmacarthurfoundation.org/explore/circular-design

Plastic and the Circular Economy, the Ellen MacArthur Foundation
https://www.ellenmacarthurfoundation.org/explore/plastics-and-the-circular-economy

New International Standards on Bamboo Structure
https://www.inbar.int/iso-22156-2021/

Unit 3: Technology for a consumer-empowered Circular Economy

3.1 Context

Enabled by information technologies, businesses and consumers alike can enjoy ever-greater opportunities to design, build and choose from circular products and services. This Unit will focus on the innovative technologies and solutions that allow for greater transparency and efficiency across supply chains, and enable smart circular designs, which extend producer responsibility, prolong product lifetime and total utility value. To better understand the sustainability impacts of products across the whole value chain, this Unit will also introduce the Life Cycle Assessment (LCA) methodology and other qualitative and quantitative methods of material flow analysis.

3.2 Learning objectives

After completing this Unit, participants will be able to:

- Outline the concept of material flow analysis and lifecycle assessment, and their applications in achieving a circular transition;
- Explain how technology can drive business innovations through enabling greater transparency and efficiency across the supply chain;
- Discuss the roles of disruptive technologies in shaping consumer behavior changes and promoting communication and education strategies.

3.3 What gets measured, gets managed

We start this Unit by introducing the concept of Material Flow Analysis (MFA) and Life Cycle Assessment (LCA). Methodologies such as MFA and LCA are useful qualitative and quantitative tools for analyzing material flows and their associated environmental impacts at a product or system level. The findings from such analyses can support evidence-based environmental policymaking and inform business decisions promoting circular strategies. Importantly, quantifying the overall material, resource and environmental impacts of products and services allows for greater transparency across product value chains, which can enable and empower individuals to make responsible consumer choices and embrace circular lifestyles.

Material Flow Analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system, defined in space and time[59]. MFA consists of the following steps[60]:

(1) Identify the key issues and segments involved in the material flow.

(2) Conduct a system analysis, focusing on the relevant materials, elements (indicator substances), processes and system boundaries.

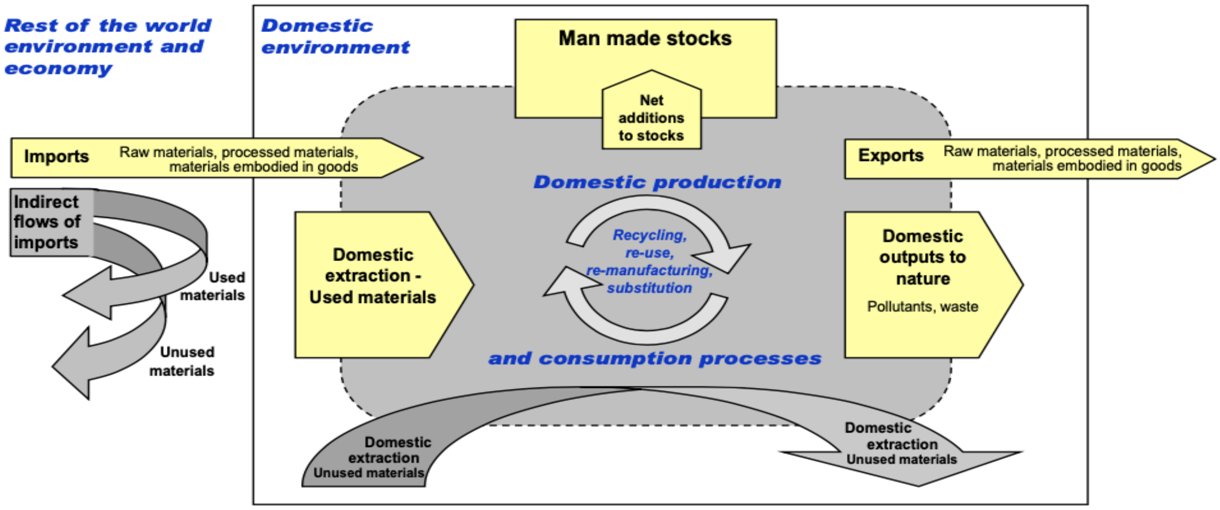
(3) Quantify the flows of matter and elements.

(4) Identify the weaknesses in the system.
(5) Develop the scenario map and interpret the results through evaluation.

MFA can be applied for economy-wide and business-level analysis.

An economy-wide MFA examines Domestic Material Consumption (DMC), which is defined as the quantity of materials used (or consumed) within a territory throughout a given time (OECD UN Stats, **Figure 10**)[61].

DMC = Domestically extracted raw materials + imported materials – exported materials



• *Figure 10: Economic-wide material balance and flow scheme*
Source: OECD, MFA[61]

The International Resource Panel's Global Material Flows Database is an authoritative source on global materials extraction and trade[62]. Using direct and consumption-based material flow indicators, the Database can easily track and compare changes in the pattern and rates of global resource use.

When applied at the business level, the MFA can monitor material flows at various operational levels for a company, a plant or an operational process. It can help businesses identify wasteful material flows and implement efficiency measures to reduce material consumption and waste.

Input-Output Analysis (IOA) is one of the fundamental tools of MFA (the System of integrated Environmental Economic Accounting, SEEA). IOA is based on physical input-output tables that record material flows to, from and through the economy by economic activity and by final demand category. Globally reputable IOA databases include Eora, GTAP, EXIOBASE, WIOD, and OECD-ICIO.

MFA can be used for many purposes including environmental impact assessments (EIA), waste management, and nutrient management in watersheds. For instance, Substance Flow Analysis (STAN), an open-source software developed by the Vienna University of Technology, can perform an MFA-based assessment of the environmental values of materials[63]. Applying the STAN methodology, and by modelling nitrogen and phosphorus fluxes, Alukwe was able to analyze the pollutant flows in Nairobi's urban water systems, identify major nitrogen and phosphorus emission sources, and suggest relevant investment and technology solutions to reduce the city's water pollution (Alukwe 2015)[64].

Life Cycle Assessment (LCA) is a useful analytical tool to assess the material requirements and potential environmental impacts of products and services during their life cycles. LCA can be applied following a standard method of ISO 14010 (OECD; MFA).

A wide range of LCA databases, at global, national, sectoral levels, exist to provide data to support the process of LCA. These include the Swiss Ecoinvent Life Cycle Inventory Database[65], the European Reference Life Cycle Database (ELCD)[66], the US NREL-USLCI Database, the Korea LCI database, and the Chinese Reference Life Cycle Database (CLCD)[67]. Research institutes and businesses are also developing and using industry- and product-specific LCA databases to advance innovation. Such efforts include the LCI Database developed by Tongji University on alternative fuels for Chinese automobiles, and the LCA database for steel products developed by China Bao Steel.

The purpose of LCAs is to determine the full range of environmental impacts attributable to a product. This allows for a full comparison of the true environmental costs between products and services (Kloeper 2008)[68]. Consider, for instance, the various options for grocery shopping bags. A LCA study conducted by the Danish Environmental Protection Agency finds that in order to "break-even environmentally with regards to a fossil fuel-based single-use plastic bag", one should use a polypropylene bag for 37 times, a paper bag for 43 times and a cotton bag for 7,100 time[68, 69]. This suggests that the cotton bag has the highest environmental footprint.

Nevertheless, the LCA methodology also has limitations. For instance, it does not take into consideration the material criticality, efficiency and potential for replacement of some of the critical raw materials that go into the renewable energy sector's value chains[70].

3.4 Building a transparent circular supply chain

While the circularity gap (as discussed in Unit 1) has yet to be closed, the latest information technologies are bringing solutions for greater transparency across material supply chains. With technologies like Internet of Things (IoTs), big data analytics, and blockchain, businesses and consumers can have better access to critical information such as material flows and the embedded ecological footprint of products and services. This can enable circular designs and activities in the supply chain.

For instance, using the power of data and algorithm, AI could make after-sales maintenance services more predictive and prescriptive, and greatly enhance "reverse logistics" to facilitate activities such as repair, refurbish, repurpose and recycle. Think of the supply chain of consumer electronics: AI could assist with a quick and thorough assessment of used devices and suggest different circular options for further use to manufacturers and consumers. Combining data such as market demand for reuse, availability of spare parts and recycled material prices, AI algorithms can perform a more prescriptive analysis of the benefits of resale, repair, refurbishment, remanufacturing or recycling solutions. This improves consumer satisfaction and the efficiency of e-waste reverse logistics (EMF 2019)[71].

Another AI-enabled technology is now being applied to reduce food waste in the food supply chain. In developed countries, more than 40% of food waste happen at the retail and consumption stages. For instance, food becomes waste when consumers or grocery shop owners discover that the food on shelf is expired. To address such food waste problems, food companies and grocery stores are using frontier technologies and data software to optimize their supply chain management. The grocery chain Carrefour, for example, has integrated AI solutions to manage their food supply chain using an SAS Viya AI system[72]. SAS Viya provides Carrefour with cost-efficient solutions such as multi-channel distribution and inventory optimization to reduce waste and create value. The SAS AI technology can process a variety of data from the Carrefour Supply Chain Information System and offer optimized solutions to continuously improve the work and forecast accuracy of the supply and planning teams. Overall, the accurate forecasting of food demand in each grocery store over time is strategically important to improve the efficiency, logistics and distribution of food products. The location of suppliers also matters in making the supply chain efficient, especially with regards to products with a short shelf life.

Disruptive technologies like blockchain can improve the traceability of products and services. This can enable more transparent and virtually "shortened" supply chains, which may not only bring environmental benefits, but also equity for suppliers, particularly small-scale farmers[73]. Accenture, for example, imagines a blockchain-enabled supply chain that links consumers directly with small-scale farmers who commit to sustainable farming practices (**Figure 11**).

- *Figure 11: A circular supply chain enabled by blockchain*
  Source: Accenture.com[73]

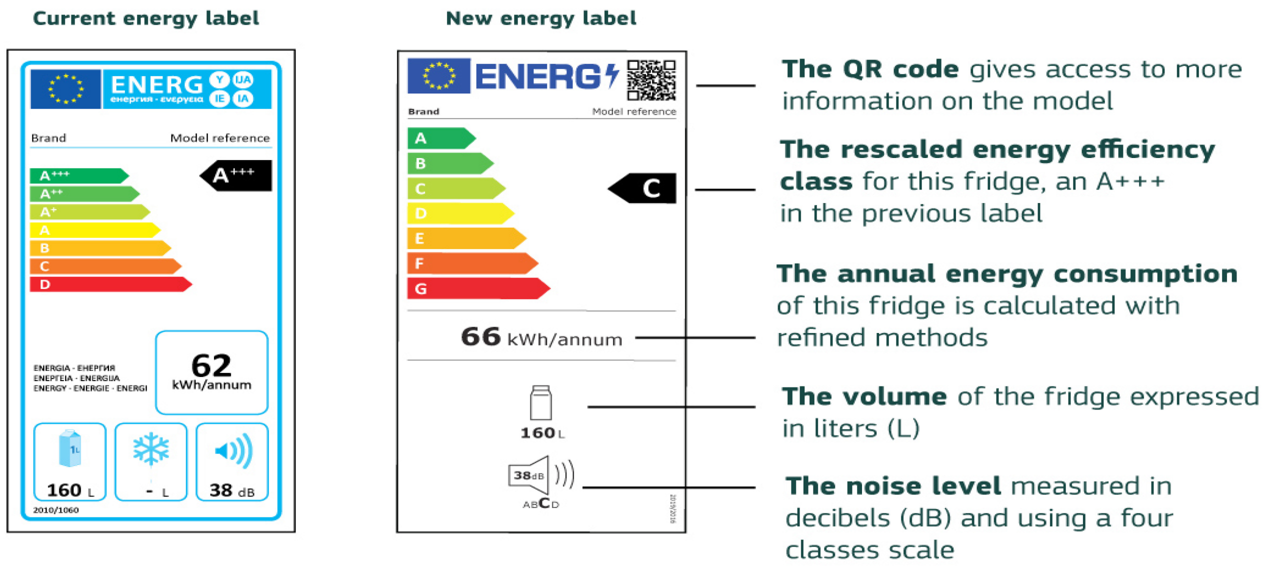
A recent survey conducted by Gartner finds that supply chain leaders are already considering and even using a combination of technologies, such as advanced analytics, Artificial intelligence and blockchain, to advance circular economy strategies[74].

Nevertheless, these new technologies, particularly the mass deployment of disruptive technologies, may have various negative consequences. For instance, they may present social concerns relating to data privacy and unequal access (this will be further discussed in Unit 5). They may also present environmental concerns. For example, the data centers that process and store massive amount of data on a daily basis are extremely energy intensive; in 2018, the world’s data centers consumed a total of 198 TWh electricity[75]. Thus, their carbon footprints need to be taken into consideration in the lifecycle assessment of the digital industry. Moreover, to mitigate these concerns, a whole-system approach may be required. New standards and global efforts are also needed to guide the industry transition towards renewable energy sources.

3.5 Shaping a circular lifestyle: a consumer’s choice

Students, farmers and policy makers alike, we have all been a consumer in our lifetime. Thus, the collective choice of millions of consumers is a driving force in the transition to a circular economy. Responding to consumer pressures, legislators may enact environmental policies and regulations to protect human health, curb polluting behaviors and incentivize green activities. Businesses, as a result, may also promote technological innovation and investment in circular business models to meet consumers’ demands.

The European Union has long been a champion for developing consumer communication tools (e.g., eco-labels, bio-based product certification and standards) to educate and empower consumers on sustainability issues. As outlined in the new EU Circular Economy Action Plan, the Commission is working towards establishing a new “right to repair” policy that will “ensure consumers receive trustworthy and relevant information on products at the point of sale, including on their lifespan and on the availability of repair services, availability of spare parts and repair manuals”. Another example is the new EU energy labelling scheme aimed at improving the energy efficiency of products and saving energy costs for households (**Figure 12**) . The EU energy labels were first introduced in 1994, and evolved to include a comparative scale from level A (most efficient) to G (least efficient) in 2004. With more energy-efficient products entering the market, the EU updated the label requirements to include additional criteria in 2019. These new requirements and eco-design standards are estimated to bring energy savings of approximately 230 million tonnes of oil equivalent (Mtoe) by 2030.

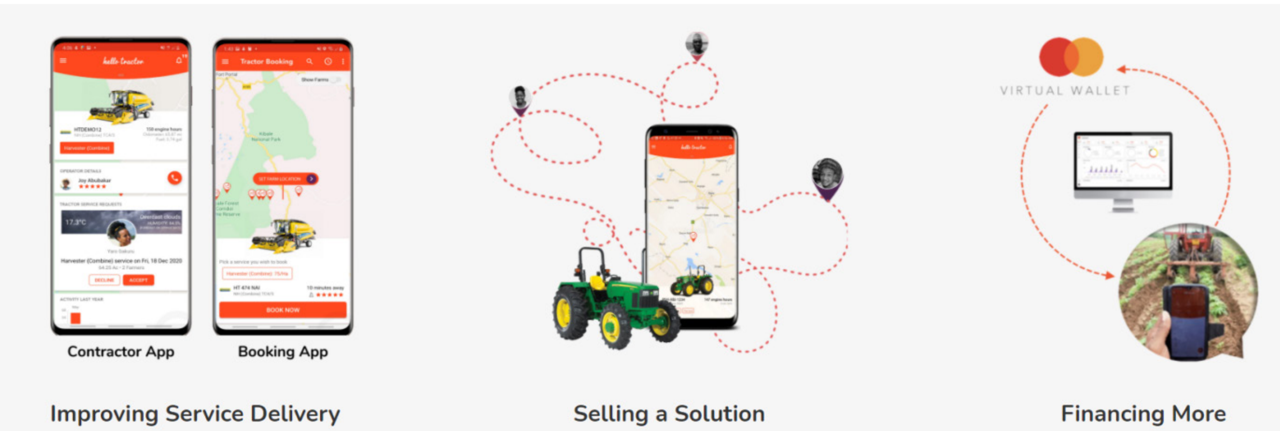


The energy labels for a fridge without freezer

- *Figure 12: An example of EU energy label for a fridge without freezer*
  Source: EU Circular Economy Action Plan, 2020[76]

With the emergence of technologies such as mobile technology and the Internet of Things (IoT), people and even devices are increasingly connected, allowing for the creation of a sharing economy (an economic model that describes peer-to-peer (P2P) based activity). This represents a paradigm shift in consumer culture from ownership to "the right to use". In a sharing economy, community-based online platforms can allow users to acquire, provide, or share access to goods and services without having to purchase full ownership. This improves resource efficiency. In particular, large cities with high population densities and limited resources are often optimal contexts for promoting a sharing economy. For instance, the global membership of urban car-sharing schemes has seen an annual rate of up to 65% (OECD 2019)[77].

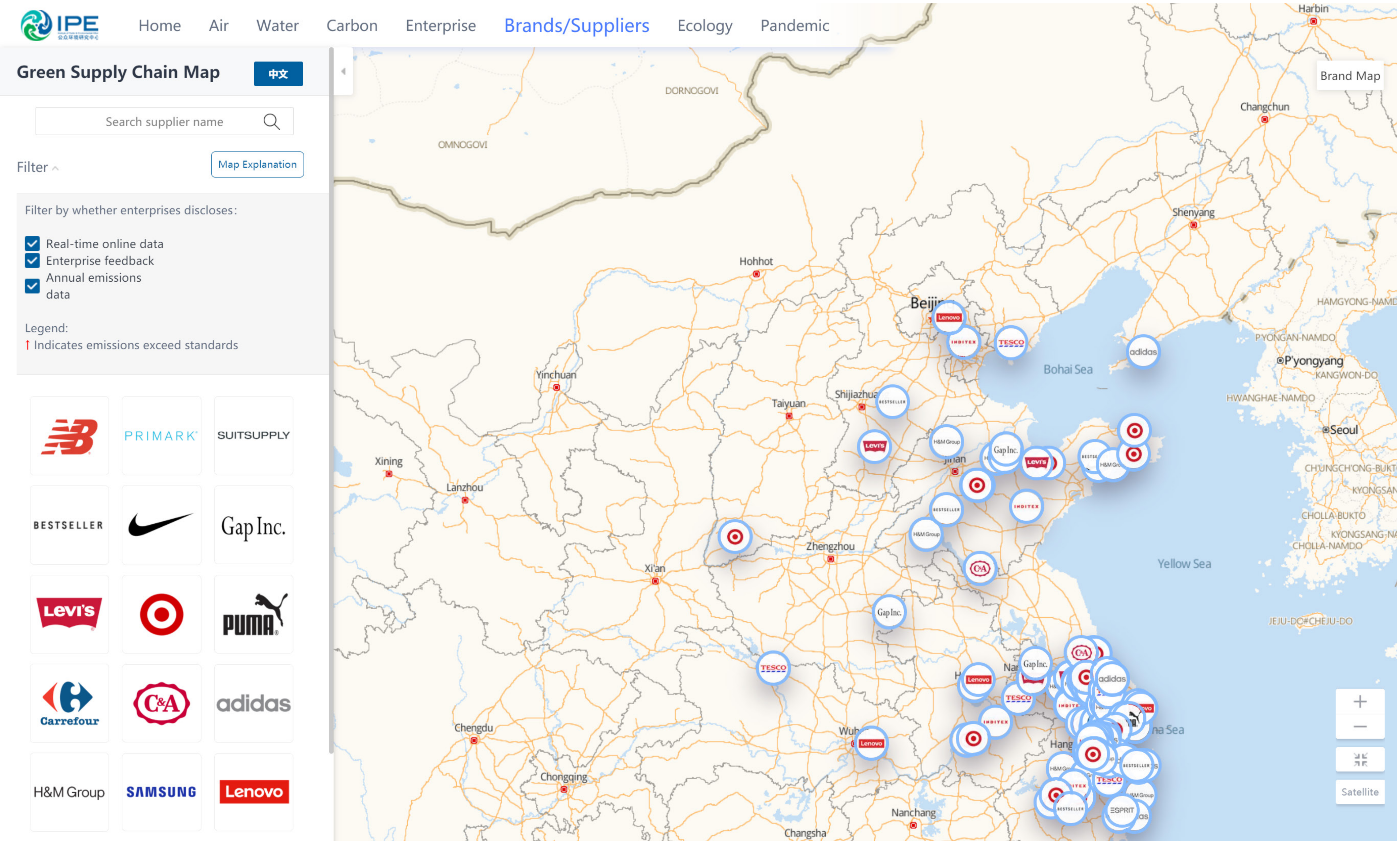
Often, innovative circular business models based on the concept of a sharing economy are welcomed by small-scale farmers. For instance, tractors can allow farmers to prepare fields in only 8 hours whereas manually, it could take up to 40 days. However, the cost of owning a tractor is often unaffordable. In response to this problem, the company Hello Tractor, which operates in Kenya, Mozambique, Senegal, Tanzania and Bangladesh, has developed a business model to sell tractors to contractors who then rent them out to farmers in need (**Figure 13**). Farmers can request a tractor with a text message through the Hello Tractor online platform. The tractors are installed with GPS, allowing owners to monitor the location of their assets, the routes travelled, fuel consumed and maintenance required. Founded in 2014, Hello Tractor has reached 240,000 smallholder farmers within just a few years of operation and their technology has been installed in 75% of commercial tractors entering Nigeria.



- *Figure 13: The Hello Tractor communication system*
Source: Hello Tractor | Break Ground[78]

In China, "Blue Map", a mobile App developed by the Institute of Public and Environmental Affairs (IPE), allows users with one click to access the environmental performance and emission data of thousands of brands and their suppliers, many of which are multinational brands with extensive supply chain presence in China. The environmental transparency enabled by the app has the potential to empower consumers in making responsible choices and promote a circular lifestyle (**Figure 14**)[79].

As global supply chains become more complex and often more fragmented, consumers may find it difficult to understand the environmental impacts associated with their purchases. As discussed in this section, digital technology solutions can help bridge this information gap. With an increasing mobile-user base and increasing screen-times, innovative digital tools such as smartphone apps and social media platforms, can support more effective consumer communication, and enhance consumer participation in a circular econo-



• *Figure 14: A screen snapshot of the the Institute of Public and Environmental Affairs Green Supply Chain Map*
Source: www.ipe.org.cn[80]

3.6 Exercise

(1) How can MFA and LCA be used to promote circular strategies in the business and policymaking context?

(2) Discuss the limitations of LCA and suggest ways in which these may be addressed.

(3) Using a lifecycle assessment approach, pick one type of consumer goods, such as a mobile phone, a pair of blue jeans, or an electric vehicle, and research the environmental impacts it has in its whole lifetime. Identify the part or process that may have the biggest environmental impact. (Note: take reasonable assumptions as needed in the LCA exercise. The results are not meant to be accurate, but indicative).

(4) Take the questionnaire on the WWF website WWF Footprint Calculator to calculate your individual environmental footprint. Then, identify three behavioral changes you could adopt to lower your footprint.

(5) Using examples, explain how consumers play a role in the transition towards a circular economy, and describe how technology may facilitate this.

(6) Using examples, explain how information technologies can contribute towards shaping more transparent and circular supply chains.

(7) Discuss the social and environmental implications of new information technologies and suggest how they may be addressed.

(8) Using examples, explain how individuals can change their daily behavior to contribute to a circular or shared economy.

3.7 Learning materials

Practical Handbook of Material Flow Analysis
https://link.springer.com/chapter/10.1007/978-94-017-7610-3_7

Life Cycle Assessment (LCA) – Complete Beginner's Guide
https://ecochain.com/knowledge/life-cycle-assessment-lca-guide/

Global Material Flows Database
Global Material Flows Database | Resource Panel

UNEP & Consumers International (2020). "Can I Recycle This?" A Global Mapping and Assessment of Standards, Labels and Claims on Plastic Packaging.

The Circulytics Indicators – measuring circularity for companies
https://www.ellenmacarthurfoundation.org/resources/apply/circulytics-measuring-circularity

Environmental Product Declarations (EPD) Tool for the Concrete and Cement Industry
https://gccassociation.org/sustainability-innovation/environmental-product-declarations/

Unit 4: Unlocking New Value for a Circular Economy: Circular Technology Applications and Case Studies

4.1 Context

This Unit will dive into regional specific contexts and identify key sectors and technologies that can be applied in the Asia-Pacific region to promote a circular economy and sustainable consumption and production patterns.

4.2 Learning objectives

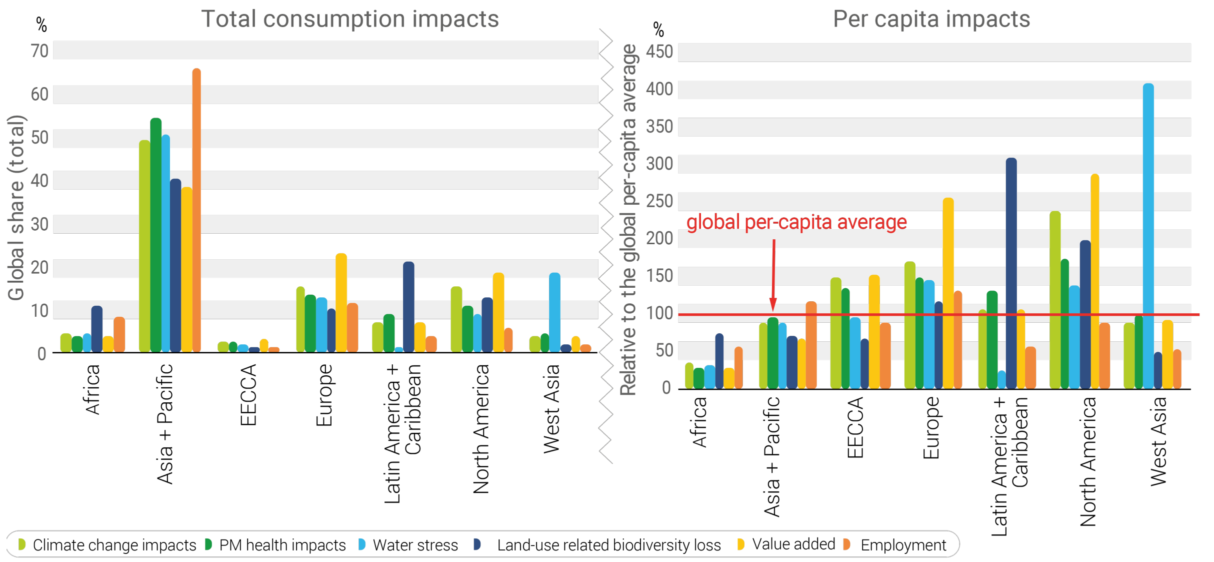
After completing this Unit, participants will be able to:

- Identify the key sectors that are critical for achieving a circular economy transition in the Asia-Pacific region;
- Discuss key circular technology applications by sector and circular technology best practices and value creation;
- Explain the concept of systems thinking and demonstrate how circular principles can be applied in complex systems for resource efficiency and waste reduction.

4.3 Circular economy in Asia: challenges and opportunities

The past few decades have seen rapid economic growth and urbanization in the Asia-Pacific region. With major infrastructure development and increased living standards for Asia's 4.5 billion people, the region is now driving the growth of global material consumption. With about two-thirds of the world's population, Asia's domestic material extraction accounts for 57% of the global total (IRP 2019)[2]. The resource sector is also important in providing employment; more than 40% of all people in Asia work in the resource extraction and production sectors (IRP 2019)[2].

This, however, comes with a heavy toll on the environment. As a result of high resource consumption patterns, the Asia-Pacific region has the largest total environmental footprint of all regions, accounting for over half of the world's climate changing GHG emissions, and Particulate Matter (PM) health, and water-stress impacts (IRP 2019, **Figure 15**)[2, 81]. Although Asia's environmental impacts are moderate at a per capita scale, a future economic trajectory that is heavily dependent on natural resource exploitation is simply unsustainable. Noting the region's heavy material footprint, a recent UN ESCAP report concluded that the Asia-Pacific region is not on track to achieve any of the 17 Sustainable Development Goals (SDGs) by 2030. Moreover, most of the sub-regions have regressed on the target of reducing material footprint, which is essential for achieving SDG 12 on Responsible Consumption and Production. Furthermore, all sub-regions, apart from the Pacific, showed either regression or slow progress on environment-related goals and targets such as GHG emissions reduction (ESCAP 2021)[82]. **Figure 16** further highlights the lack of progress on the SDG targets pertinent to the transition towards a circular economy.



Left: Total footprints as a share of total global impacts (values for all regions together add up to 100 per cent).
Right: Per capita footprint, where the 100 per cent line marks the global per capita average. Reference year: 2011
Data source: Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018).

- *Figure 15: Total consumption impacts by region*
  Source: IRP 2019[2]

7 AFFORDABLE AND CLEAN ENERGY

7 AFFORDABLE AND CLEAN ENERGY

- 7.1 Access to energy services
- **7.3 Energy efficiency**
- 7.a International cooperation on energy
- 7.b Investing in energy infrastructure
- **7.2 Share of renewable energy**

8 DECENT WORK AND ECONOMIC GROWTH

8 DECENT WORK AND ECONOMIC GROWTH

- 8.1 Per capita economic growth
- 8.2 Economic productivity & innovation
- 8.3 Formalization of SMEs
- 8.6 Youth NEET
- 8.8 Labour rights & safe working env.
- 8.10 Access to financial services
- 8.a Aid for trade
- **8.4 Material resource efficiency**
- 8.5 Full employment & decent work
- 8.7 Child & forced labour
- 8.9 Sustainable tourism
- 8.b Strategy for youth employment

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

- **12.4 Managing chemical & wastes**
- **12.5 Reduction in waste generation**
- 12.a Support for R&D capacity for SD
- 12.c Fossil-fuel subsides
- **12.2 Sustainable use of natural resources**
- 12.b Sustainable tourism monitoring
- 12.1 Programmers on SCP
- 12.3 Food waste & losses
- 12.6 Corporate sustainable practices
- 12.7 Public procurement practices
- 12.8 Sustainable development awareness

- MAINTAIN progress to achieve target
- ACCELERATE progress to achieve target
- REVERSE trend
- Insufficient data to measure

- *Figure 16: Anticipated progress on circular economy related SDG targets in the Asia-Pacific Region*
  Source: UN ESCAP, 2021, Asia and the Pacific SDG Progress Report 2021 (unescap.org)[82]

The rest of the Unit will focus on emerging technology applications and case studies in three key sectors: Energy, Water and Waste Management – all of which are critical for Asia to achieve a circular economy. Given the trend of rapid urbanization and industrialization in Asia, it will also discuss how the application of systems-thinking to urban infrastructure systems, such as industrial parks and cities, may unlock new value for a circular future.

4.4 Key sector – energy

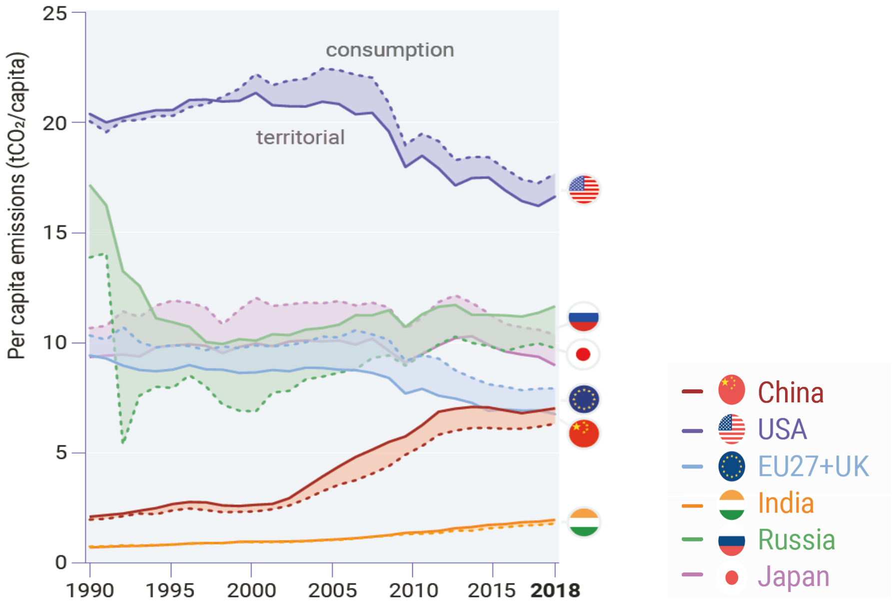
4.4.1 Global energy consumption in a warming world

Primary energy is taken directly from natural resources which have not undergone any conversion or transformation processes[84]. Most of the natural resources we use to convert into energy are in the form of non-renewable fossil fuels, the burning and use of which releases carbon dioxide, a major driver of climate change. Renewable energy, on the contrary, is derived from natural resources that are not finite or exhaustible, such as water, geothermal heat, the sun, wind, tide and waves[85].

Global energy consumption has increased dramatically since the industrial revolution. To curb climate changing carbon emissions and prevent the worst impacts of climate change, over 190 countries gathered in Paris and signed a global climate change agreement in 2015. Under the Paris Agreement, countries have agreed to take actions to limit global warming to well below 2 degrees Celsius compared to pre-industrial levels, and preferably limit the increase to 1.5 degrees Celsius[86].

However, the progress made so far has been limited. The UNEP Emissions Gap 2020 Report concluded that there is a significant gap between current National Determined Contributions (NDCs) pledges and the Paris climate goal. It expects that current NDC pledges would lead to a world with an average temperature increase of 3 ℃ or more by the end of this century.

The Report also finds that developed countries tend to have higher consumption-based emissions than territorial-based emissions (**Figure 17**), suggesting that domestic consumption patterns in developed countries are dependent on the outsourcing of materials and products possibly from developing countries with lower labor costs and lax environmental regulations. On a global scale, energy demand is still projected to increase as the developing world continues to industrialize and urbanize. This calls for strong measures addressing energy efficiency and a rapid, global scaling up of renewable energy.



• *Figure 17: Per-capita CO_2 emissions by top 6 global emitters, consumption-based CO_2 emissions (dotted line) vs.territorial-based CO_2 emissions (solid line) Source: The Emissions Gap Report, UNEP 2020*[87]

4.4.2 Energy efficiency

Improving energy efficiency can contribute to significant energy savings, and can often be implemented without major upfront investment or technology. Therefore, energy efficiency measures may be considered as the "low-hanging fruits" solutions to achieving the Paris climate goals and ensuring affordable energy access to all.

Energy efficiency measures the minimum amount of energy required by a system or equipment to provide the desired level performance. Energy efficiency indicators are sector-specific, reflecting the different processes, industrial good practices and Best Available Technology (BAT) for each sector and industry. For example, the Energy Efficiency Design Index (EEDI) is a technical measure for the minimum energy efficiency level per capacity mile by different ship types and sizes. The EEDI was announced as a mandatory requirement for all ships by the International Maritime Organization (IMO)[88].

Another important indicator is the Energy Efficiency Indicator (EEI) which looks at end-use energy in the residential sector as well as the industry and service sectors. In the residential sector it includes the energy used in residential areas for heating, cooling, lighting, cooking, water heating, home appliances and other non-specified use. Also known as the Building Energy Index (BEI), EEI is a key performance indicator to measure energy performance in buildings[89]. In the industry and service sectors, the EEI includes the energy used in the processes of manufacturing, agriculture, mining, construction and services provision. The International Energy Agency (IEA) produces annual statistical reports analyzing the EEI in its member countries in order to track and improve national energy efficiency policies[90].

4.4.3 Renewable energy

By reducing carbon emissions, renewable energy is fundamental for achieving climate goals. Since 2000, the global uptake of renewable energy consumption has been highly successful, increasing from just 3 exajoules in 2000 to an estimated 161 exajoules by 2050[91]. Innovations and the accelerated application of renewable energy technologies have been driven by enabling national and regional policies and collaboration between scientific institutions and business communities. The development of renewable energy technologies not only brings economic benefits such as new job opportunities, but also improves the overall energy security and resilience of the energy system by providing energy access to isolated populations who were not previously connected to the grid.

Innovation and technology development has massively reduced the costs for generating renewable energy, making renewable energy production cost-competitive with conventional fossil fuel-based energy production[92]. With technology breakthroughs in areas like electric vehicles, there is an exciting opportunity to decarbonize mobility systems and transform the way we move and commute.

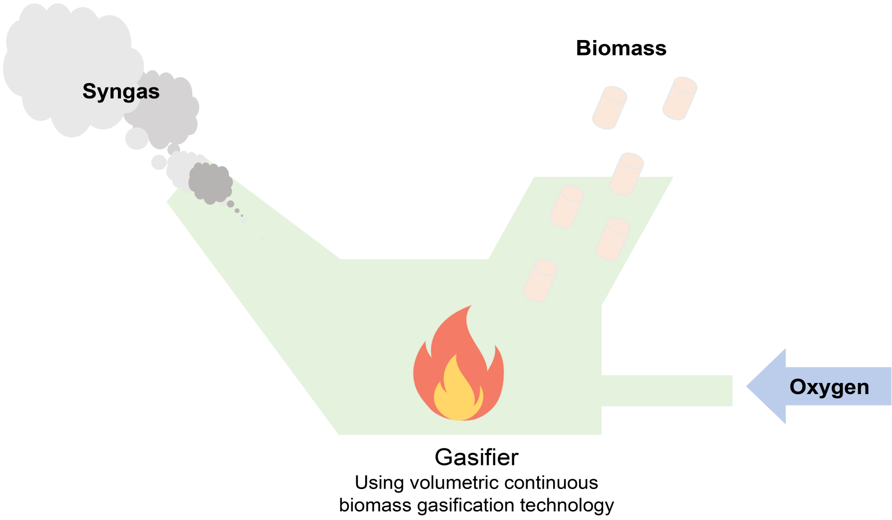
4.4.4 Case studies in energy sector

Case 1: Biomass gasification technology for local communities

The Problem: Statistics from the Ministry of Industry and Trade of Vietnam in 2017 showed that agricultural production in Vietnam generates annual agricultural wastes of about 118 million tonnes, of which only 11% is reused[93]. Using locally available renewable resources, biomass gasification technology can efficiently generate power and heat for local dwellers, while at the same time reducing the carbon emissions caused by traditional methods of rural biomass waste disposal.

The Solution: Gasification is a thermo-chemical conversion process which turns organic materials into valuable gaseous products. Biomass gasification can efficiently produce energy, heat, hydrogen and other biofuels as by-products[94]. Biomass gasification technology is also considered as a sustainable waste-to-energy solution as it transforms biomass waste (which would otherwise cause significant air pollution and health problems) into energy.

THÁI NGUYÊN, also known as BEST, is an EU-funded and Oxfam-implemented project promoting biomass gasification technology in the province of Thái Nguyên in Vietnam. The project aims to promote small-scale biochemical technology to accommodate the financial and technological capabilities of businesses, and develop a local support service system.



The Biomass gasification project by Oxfam[95]

The Benefits: The application of biomass gasification technology in the rural areas of Vietnam lowered energy costs by 50% compared to conventional sources of coal, diesel and gas. The project also introduced sustainable rural waste management technologies, and generated jobs particularly for women in local biomass businesses.

The project engaged with 2,500 agricultural processing households, 100 mechanical enterprises and 400 suppliers of biomass. Approximately 1.2 million people, half of them women, will benefit from improved income and health brought by the technology.

Case 2: Smart home technologies for greater energy-efficiency

The Problem: Electricity and heat generation are significant sources of GHG emissions, accounting for 24% of total emissions in the past decade[96]. The building sector is thus considered as the largest energy and heat consumer. Smart technologies present an opportunity to reduce the energy and heat consumption of this sector[89].

The Solution: Using the latest IoTs technology and state-of-the-art building and home management systems, automatic indoor climate control can optimize the energy systems of homes and buildings. Through optimization and analytics, this digital technology enables greater and finer control over and system efficiency of building energy and heating systems. For instance, it uses sensors to monitor the surrounding environment, making fine adjustments to make it comfortable for occupants while keeping the energy consumption low.

Furthermore, smart home technology appliances can integrate energy efficiency controls with other functions such as intelligent automation. For example, a window sensor designed by the Company Xiaomi is able to connect with other smart appliances in the room to perform the following tasks:

- Automatically turning on the lights when someone enters at night, or ringing a door bell to alert when a guest has entered.

- If the Home mode is turned off (meaning that you are not at home), the alarm will go off and the appliance will start video recording if someone breaks in; the intelligent sensor can automatically open the window to refresh indoor air and turn off the indoor air purifier at the same time. Once the windows are closed, the air purifier will be turned on again.

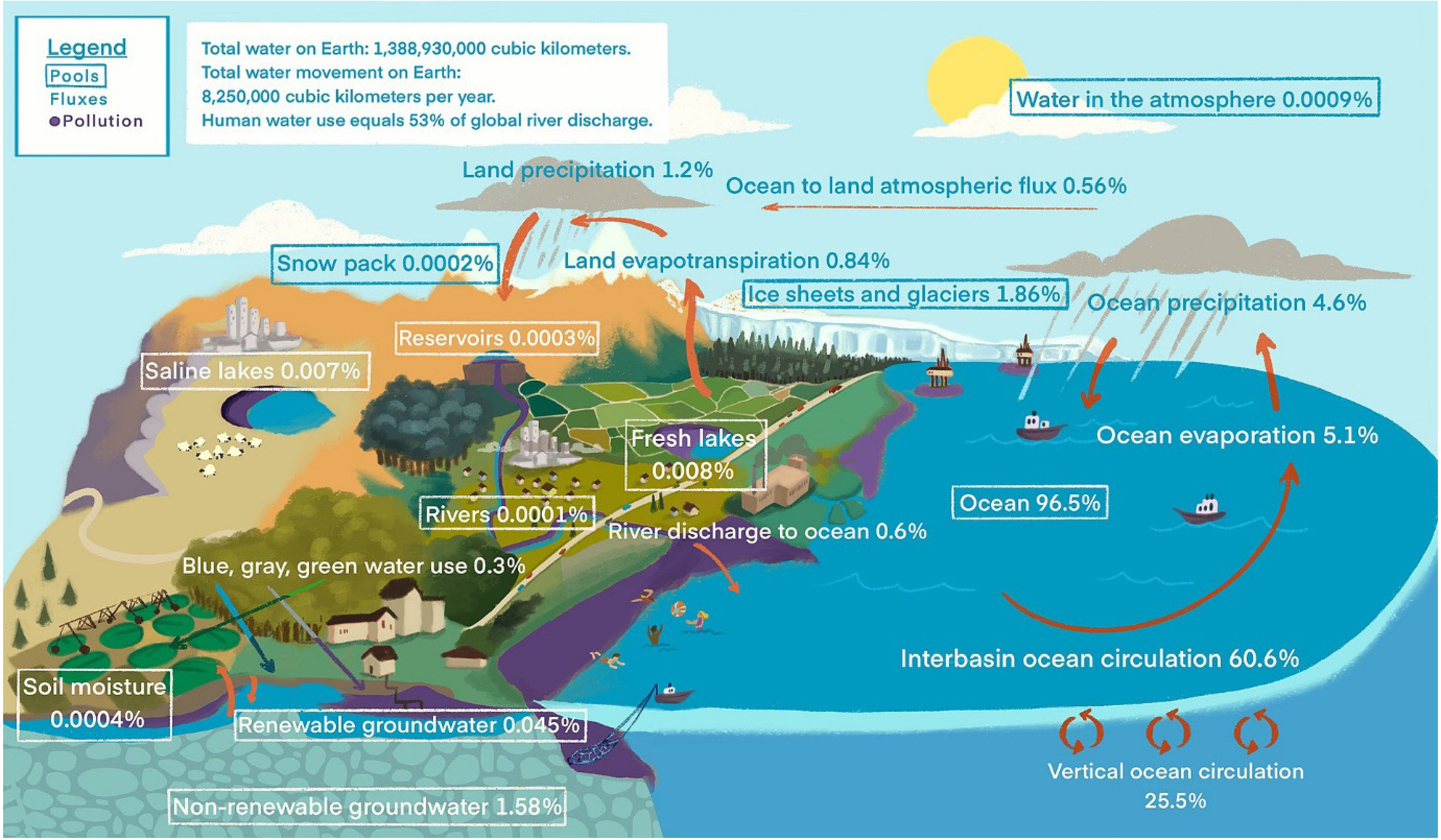
Xiaomi smart home integrated appliances[97]

The Benefits: A smart grid installed in a single building can save up to 40% of total energy used by lighting, providing huge commercial value for this technology. Tejani and Ali Mohammed et al. (2011) also concluded that the energy conservation benefits of integrated smart home technologies could reduce energy bills by a range of US$113.33 - US$227.55 per room per year[98].

4.5 Key sector – water

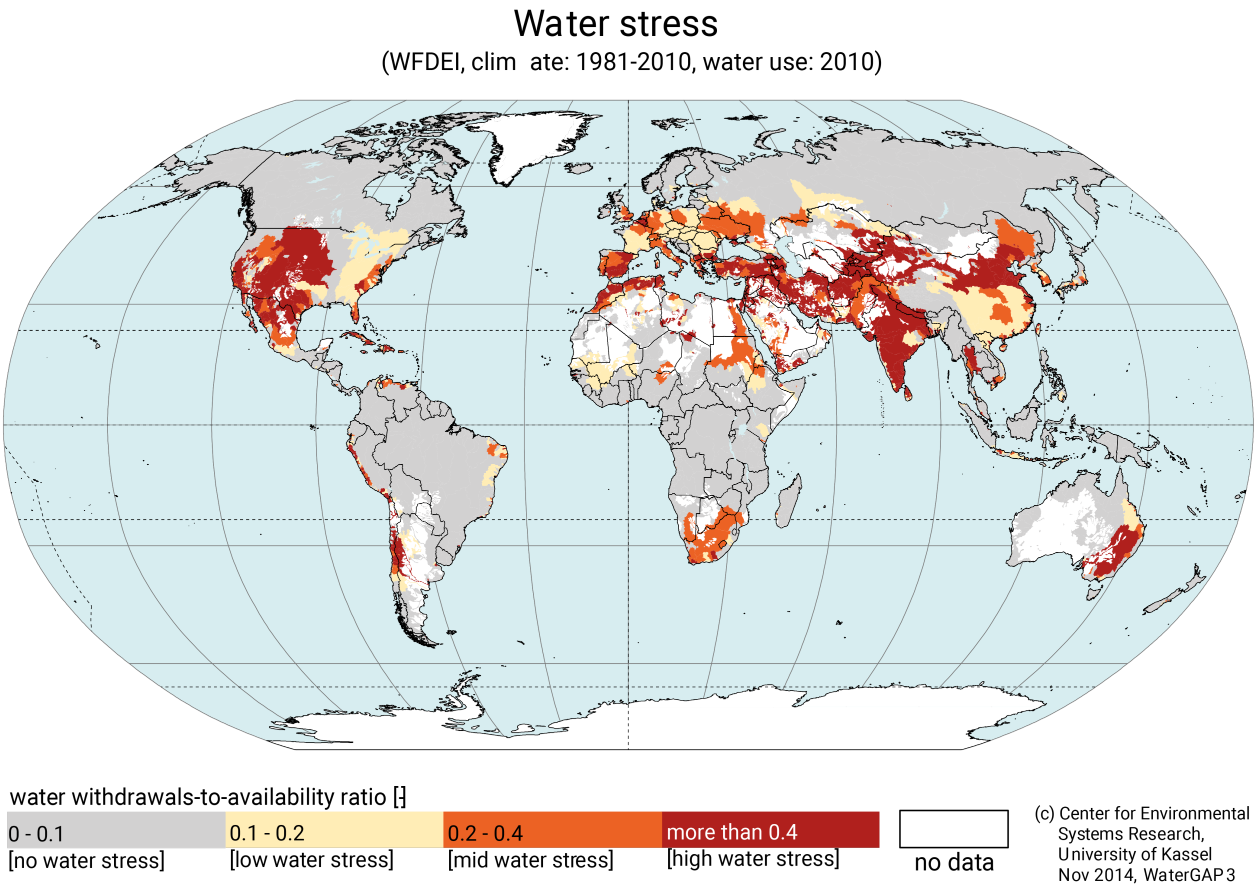
Water is implicated in most of the Sustainable Development Goals (SDGs) as being crucial to food security (SDG 2), health and well-being (SDG 3), energy security (SDG 7), sustainable cities (SDG 11), responsible consumption and production (SDG 12), climate impacts (SDG 13), life below water (SDG 14) and terrestrial biodiversity (SDG 15)[99].

Freshwater is essential for the health and well-being of people, animals, plants, and aquatic and terrestrial ecosystems (**Figure 18**). Of the total amount of earth's surface water, only 3% is drinkable freshwater; slightly over two-thirds of it is frozen in glaciers and polar ice caps. The remaining is mainly groundwater.



• *Figure 18: Water cycle on earth*
Source: Nature Geoscience, 2019, 12, 533–540[102]

Groundwater is becoming increasingly scarce globally. About 1/3 of the total groundwater available has already been extracted as drinking water for human consumption and agricultural irrigation, particularly in arid regions and during drought (Famiglietti 2014)[100]. The demand for groundwater is increasing especially in Asia and the Pacific region[101]. With increasingly severe climate change and industrial water pollution impacts to come, water insecurity in this region is anticipated. This will increase pressure on groundwater. Many parts of Asia, including most of India, Northern China, Central Asia and Eastern Australia (the Murray-Darling-Basin), are already under high water stress (**Figure 19**).



• *Figure 19: Global map of water stress*
Source: IRP 2019[2]

In relation to better managing the global water system, a circular economy promotes the following: technologies for water consumption reduction, water use efficiency and water treatment in industries. Major water technologies, such as water treatment technologies, optimized water supply systems and digitalized water distribution systems, have been developed to ensure water quality and safe water supply to households. Many of these technologies, including those related to water utility management, also consider economic and social aspects[103].

4.5.1 Case studies in the water sector

Case 3: Agricultural irrigation technology – safer and more efficient irrigation

The Problem: The sustainable management of natural resources such as forests, grasslands and wetlands are often closely linked with local agricultural practices and livelihoods. Unsustainable irrigation practices, however, may lead to increased water scarcity, pollution, and damage to the very natural resources that local, often poorer, communities depend upon.

The Solution: One method of efficient agricultural irrigation is to send water directly to crop roots in order to reduce water waste through evaporation. Drip irrigation, a type of micro-irrigation method, utilizes hoses with holes to maintain a minimum yet sufficient amount of water for crops.

With the development of mobile information technology, drip irrigation can now be remotely controlled by a mobile to precisely control the amount of water used. This makes agricultural irrigation more efficient, especially since the optimal amount of water required by each crop may vary depending on the species, soil type, sunlight exposure, precipitation levels and other environmental factors, which need to be calculated with statistical data and reliable forecasting models.

A precision mobile drip irrigation (PMDI) system[104]

The Benefits: Efficient agricultural irrigation technology can reduce pollutants from agricultural production in rural areas, promoting sustainable rural development and the implementation of nature-based solutions. Drip irrigation systems consume 30% - 50% less water than conventional forms of irrigation, and they also inhibit the growth of weeds around crops. Moreover, with the precision mobile drip irrigation system, which applies water 95% more efficiently than traditional sprinklers, water wastage from evaporation and wind drift can also be reduced[105].

Case 4: Vertical and indoor farming

The Problem: Megacities in Asia are some of the most densely populated zones worldwide. This has often led to increasing water scarcity, infertile land, low food productivity and high transportation costs from suburb farms to city hubs. To address these agricultural problems, companies like Delhi-based Triton Foodworks are using vertical farming and Controlled Environment Agriculture (CEA) technologies.

The Solution: Vertical farming not only allows for greater control of climate and nutrition conditions, but also high irrigation water recycling rates and reduced land use than outdoor farming. Vertically farmed crops also typically have enhanced nutritional value, longer shelf life, better taste, smaller water footprints, less pestcides and shorter supply chains[106].

The core of vertical farming technology is data analysis based on geoponics and agricultural sciences. Vertical farming data frameworks and analytical models enable efficient resource distribution and food production by optimizing the parameters, such as temperature, electrical conductivity and pH, for plant growth.

Vertical farming also draws on agricultural technologies such as hydroponics, aeroponics and aquaponics. Hydroponics is the science of growing plants without soil. Nutrients are supplied to plants through water, with or without a growing medium. Aeroponics is the method of growing plants without a growing medium. The roots of plants are suspended in the air and nutrients are fed through a fine mist. Aquaponics is the integrated solution of aquaculture and hydroponics in a recirculating system. By growing plants and fish together, the wastes and metabolites produced by cultured fish become nutrients for plant growth.

The Benefits: Triton Foodworks' vertical farm uses proprietary hydroponics, which uses only 2% water, 1% land and zero chemicals compared to conventional farms[107]. AeroFarms, a data-driven indoor vertical farming company, uses proprietary aeroponic technology to mist plant roots with targeted nutrients, water, and oxygen in a closed loop system. This uses even less water than hydroponics, as well as a fraction of the fertilizers. AeroFarms use 95% less water and approximately 50% less fertilizers than traditional farms, whilst also optimizing temperature, humidity and nutrient levels[108].

Aeroponics, AeroFarms[108]

Case 5: Reducing wastewater in the textile supply chain

The Problem: Asian countries like China, Vietnam and Cambodia are becoming important manufacturing hubs for global textile and apparel brands. In 2018, China's textile and apparel exports accounted for a third of the world total[109]. This rapid growth, however, also brings environmental challenges such as the use of hazardous chemicals in textile production processes, waste-water discharge and water pollution. Printing and dyeing, for instance, are important value-added processes in the textile value chain, however, they carry great environmental impacts and challenges; waste-water discharge from these processes accounts for 80% of all waste water generated in the textile value chain.

The Solution: Driven by tightened environmental regulations and growing consumer awareness, the textile industry in China has piloted and implemented several innovative technologies to improve energy conservation, waste reduction and recycling. These include, for instance, low temperature bleaching, salt-free dyeing of cotton fabrics, continuous open-width pre-processing, washing of knitted fabrics and yarn coating dyeing. Major research breakthroughs have also been made on the use of enzyme refining, short wet steam dyeing, foam dyeing, knitted fabric open-width dyeing, ultrasonic dyeing, plasma technology, and non-aqueous medium dyeing (EMF 2020)[110].

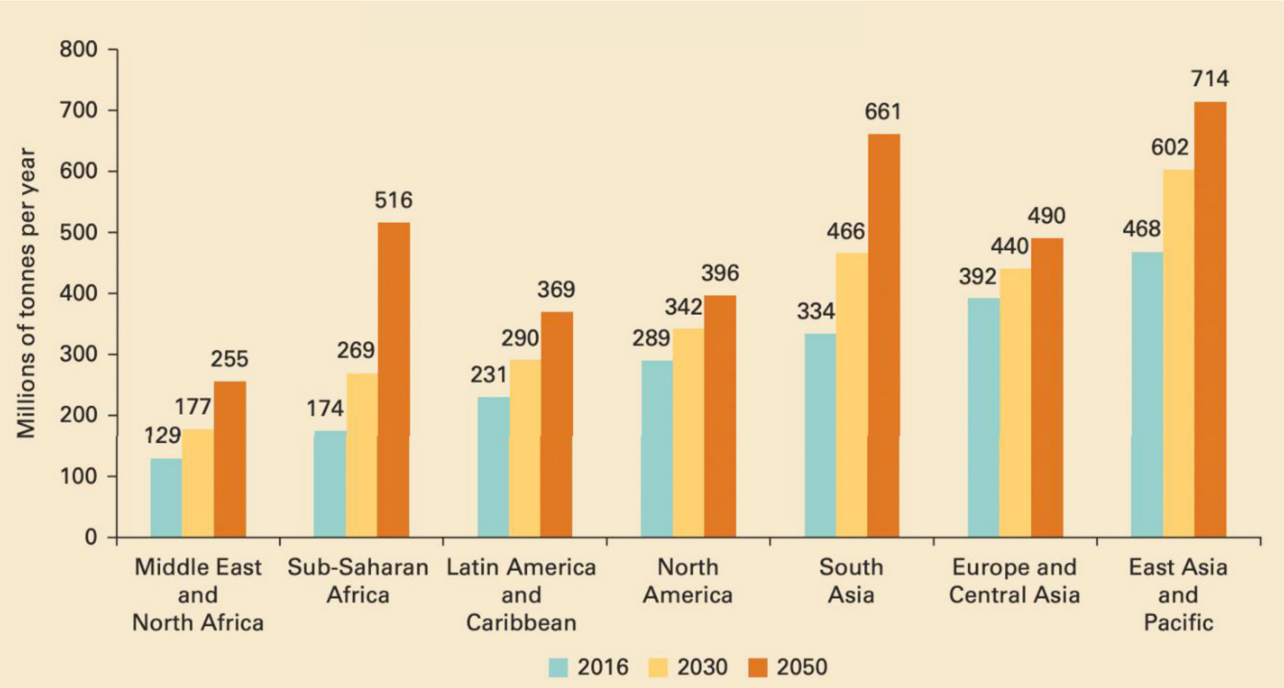
With advancements in digital and automation technologies, the industry has also been able to greatly improve its automatic control systems, allowing for precise dosing and transportation of chemicals, online collection and automatic control of process parameters etc. One innovative dyeing process, developed by Shandong Companion Group Co., Ltd., China Academy of Mechanical Science and Technology Group and Lutai Textile Co., Ltd, appears to be the world's first to pioneer a fully automatic digital dyeing process for cheese packaging. Highly efficient and automated, the process could save up to 70% of water per ton of yarn, compared to traditional dyeing, whilst also reducing 45% of electricity use and 58% of gas use. The production efficiency could also increase by 28% and overall cost reduced by 30%. The technology won first place in the 2014 National Science and Technology Progress Award in China.

Latest technological development in the dyeing industry can possibly bring a sea of change to conventional dyeing processes. Dutch start-up DyeCoo, for instance, has developed an industrially-proven dyeing technology that uses CO_2 as the dyeing medium in a closed-loop process[111]. The process has the potential to transform the dyeing process to be water-free and chemical-free. Furthermore, it also works well with polyester, which is produced mostly in Asia. DyeCoo currently operates nine machines in Thailand and Taiwan, and plans to install three new machines in Vietnam.

The Benefits: During its 12th Five-Year Plan (2011-2015) period, China has piloted and scaled up a large number of new energy-conservation and emission-reduction technologies for textile production. The freshwater intake for textile printing and dyeing processes, for example, has decreased from 2.5 tons to less than 1.8 tons per 100 meters of cloth, and the water recycling rate increased from 15% to more than 30%. The trend has continued to improve significantly during the 13th Five-Year Plan (2016-2020) period.

4.6 Key Sector – waste management

With a large population base and rising living standard, the Asia-Pacific region currently generates the most waste out of all regions in the world, and will continue to experience a fast increase in waste generation in the coming decades (Kaza et al., World Bank 2018)[112]. Rapid urbanization has resulted in a significant increase of municipal solid waste in Asian cities – home to nearly 50 per cent of the region's population. However, except for a few high-income countries, many Asian cities still suffer from low waste collection rates owing to insufficient waste management infrastructure (UNEP-IETC AWMO, 2017)[113].



- *Figure 20: Projected solid waste generation by region (total projected waste generation)*

Source: Adapted from Figure 2.7 of the World Bank Publication What a Waste 2.0 (Kaza et al. 2018)[114]

Apart from the challenges faced with the municipal solid waste, other waste streams such as e-waste, food waste, construction and demolition waste (C&D), and plastic waste are of high concern in Asia.

- In 2016, 45 million tonnes of electronic waste (e-waste) was generated, with an estimated value of EUR 55 billion in raw materials. A significant portion of this value can never be recovered, as only 20% of this waste is collected and recycled appropriately.
- Globally, nearly 30 % of fruit, vegetables, grains, meat, and packaged foods produced for human consumption is wasted or lost throughout the food supply chain or during consumption, with an estimated annual cost of US$ 1 trillion[115]. Food waste also accounts for 6–10% of global, anthropogenic GHG emissions, posing an environmental problem for many countries.
- Plastic waste in the ocean, which makes up 60-80% of all marine debris also has direct economic impacts. The Asia-Pacific Economic Cooperation (APEC) estimates that the cost of plastic waste to the tourism, fishing and shipping industries is US$ 1.3 billion in Asia alone (UNEP 2014, UNEP-IETC 2017)[116, 117].

Eliminating waste is an important element of a circular economy. Applying circular design principles, fostering innovative circular business models (such as reuse, repair, repurpose) and advanced recycling technologies can realize significant economic gains, generate employment, reduce risks to humans and ecosystems and achieve higher productivity and resource security in the Asia-Pacific region.

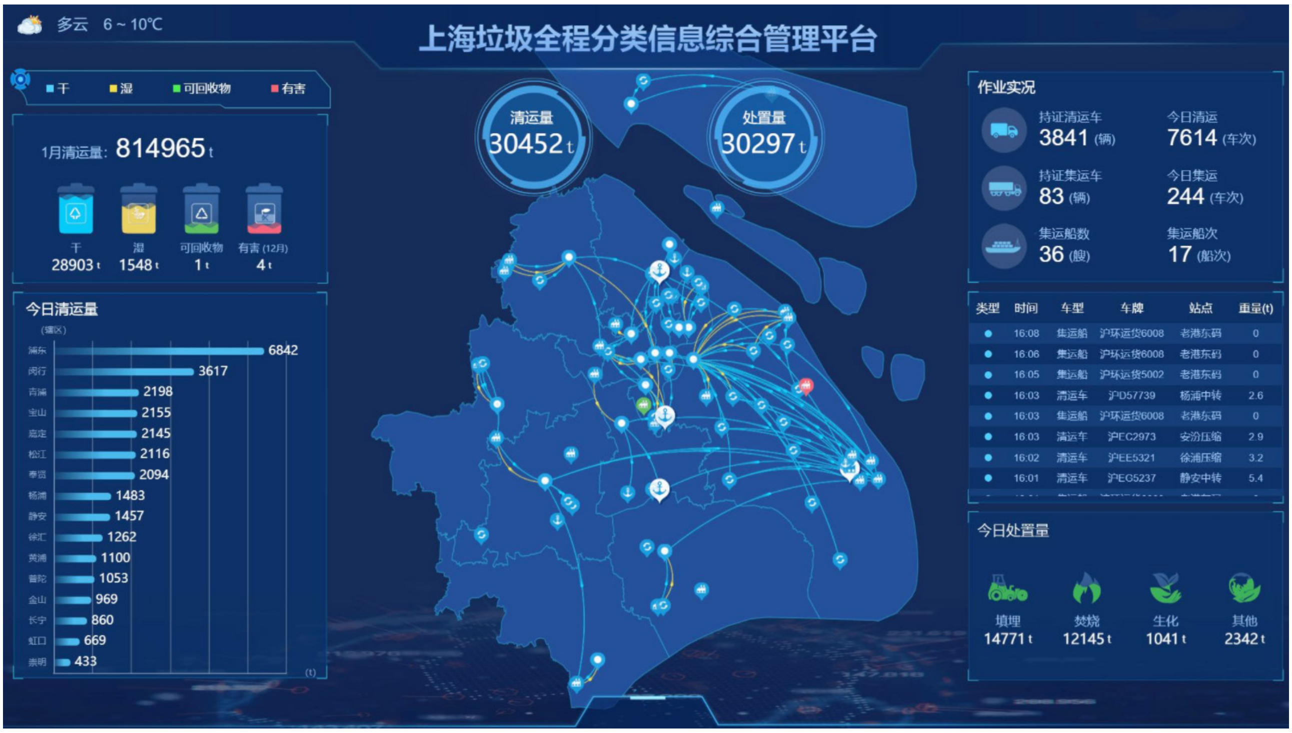
4.6.1 Case studies in the waste sector

Case 6: Integrated municipal waste management system for mega-cities

The Problem: By 2017, the city of Shanghai generated nearly 9 million tonnes of municipal waste annually and was the largest waste generator of all Chinese cities. While 100% of municipal wastes were collected and treated, the majority (80%) were incinerated or sent to landfills, and less than 20% was recovered/recycled. With existing treatment facilities close to maximum capacity, and increasing waste generation resulting from rising living standards, city planners face a tough question on whether to invest and expand the end-of-pipeline treatment facilities or shift towards establishing a comprehensive waste management system that focuses on effective reduction at source, sorting and recycling.

The Solution: Well, the answer is yes to both approaches. The city government has put forward a detailed action plan (2018-2020) establishing a "whole-process recycling system", to significantly improve the sorting and collection of "wet-waste" (biodegradable kitchen and food wastes) from other non-recyclable waste. This is the single most important strategy for reduction at source. By May 2020, the city has collected 9796 tonnes of wet waste daily, an increase of 73% from 2019.

However, setting up an efficient sorting and recycling infrastructure system in a mega-city like Shanghai may present challenges. Given the city's high population density and expensive land prices, a careful and integrated planning approach is needed to minimize unpleasant experiences (e.g., odors, waste contamination) in communal collection and sorting networks. To address such problems, modern information analytics has enabled decision-makers to track near real-time material flows of different type of waste collected, sorted, and treated, to gain a better overview of the whole-process waste classification information and to support integrated waste management within a complex system. An example of this is the Shanghai Municiple Integrated Waste Management System developed by Shanghai Municipal People's Goverment.



Shanghai Municipal Integrated Waste Management System
Source: Shanghai Chengtou Environment

Moreover, a set of supporting policies have been developed to incentivize business and consumer behavior changes, such as licensed operation, subsidies for reduction activities, Extended Producer Responsibility (EPR), as well as green public procurement.

Wet-waste is an ideal feedstock for Anaerobic Digestion technology, a biological process whereby organic matter is broken down in the absence oxygen in a sealed container (also called “anaerobic digester”) to produce biogas and biofertilizer for energy and other purposes[118].

The Benefits: With an improved waste collection and sorting system in Shanghai, especially for wet-waste, new investments in anaerobic digesters have been made for use in treatment facilities. For instance, a new plant with 500t/d processing capacity of wet-waste has been set up in the district of Songjiang, suburban Shanghai. The plant is located in the Tianma Industrial Park, where material flows are circulated in a close loop within the park, and energy and utilities are supplied through integrated, park-wide infrastructure. For instance, by collecting the biogas generated from the anaerobic digester and the incinerator, the Tianma plant increased its elecriticity generation by 100,000 kwh with an annual cost saving of around US$2.8 million, and an estimated annual carbon emission reduction of around 300,000 ton.

Tianma Industrial Park
Source: Provided by Shanghai Environment Group Co., Ltd.

Case 7: Digital e-commerce solutions for food waste reduction and poverty alleviation

The Problem: Globally, uneaten food could feed approximately 2 billion people – more than twice the number of undernourished people worldwide[119]. Furthermore, the World Food Programme (WFP) also highlights global food waste as a major source of carbon emissions, ranking third after the USA and China. Therefore, reducing food waste by improving efficiency in food production, consumption and distribution processes can contribute to the global poverty alleviation efforts as well as fighting climate change. Contrasting with the primary food waste causes in industrialized countries, 40% of food losses occur at post-harvest and processing levels in developing countries. Globally, post-harvest food loss is a leading cause of food insecurity[120].

The Solution: One of the major causes of food losses in the post-harvest period is inadequate storage and poor time-bound linkage between farmers and the targeted market. Helping to solve this issue, increasing coverage of mobile internet services in rural areas in many developing countries has enabled small-scale farmers to improve their access to the market by facilitating direct connection and communication to end-consumers. This can improve overall efficiency in the post-harvest period.

In China, for instance, an integrated e-commerce platform for agricultural products and food processing[121] was established under government guidance to promote public procurement directly from targeted rural areas to improve rural livelihoods while reducing post-harvest food waste. The online platform is enabled by big data analytics, which incorporates data such as tourist routes and local and cultural specialties. It is open to public departments and individuals, allows for online bidding and makes every transaction detail publicly available.

The Benefits: The E-commerce platform has nearly 12,000 qualified and approved small-scale suppliers, most of them from relatively poor rural areas in China. It links together all stakeholders across the food value chain, from those in food production to distribution and retail, generating significant daily transaction. For instance, in the first of week of June 2021, daily sales amounted between RMB 55-72 million (or, 8.5-11 million US$/day).

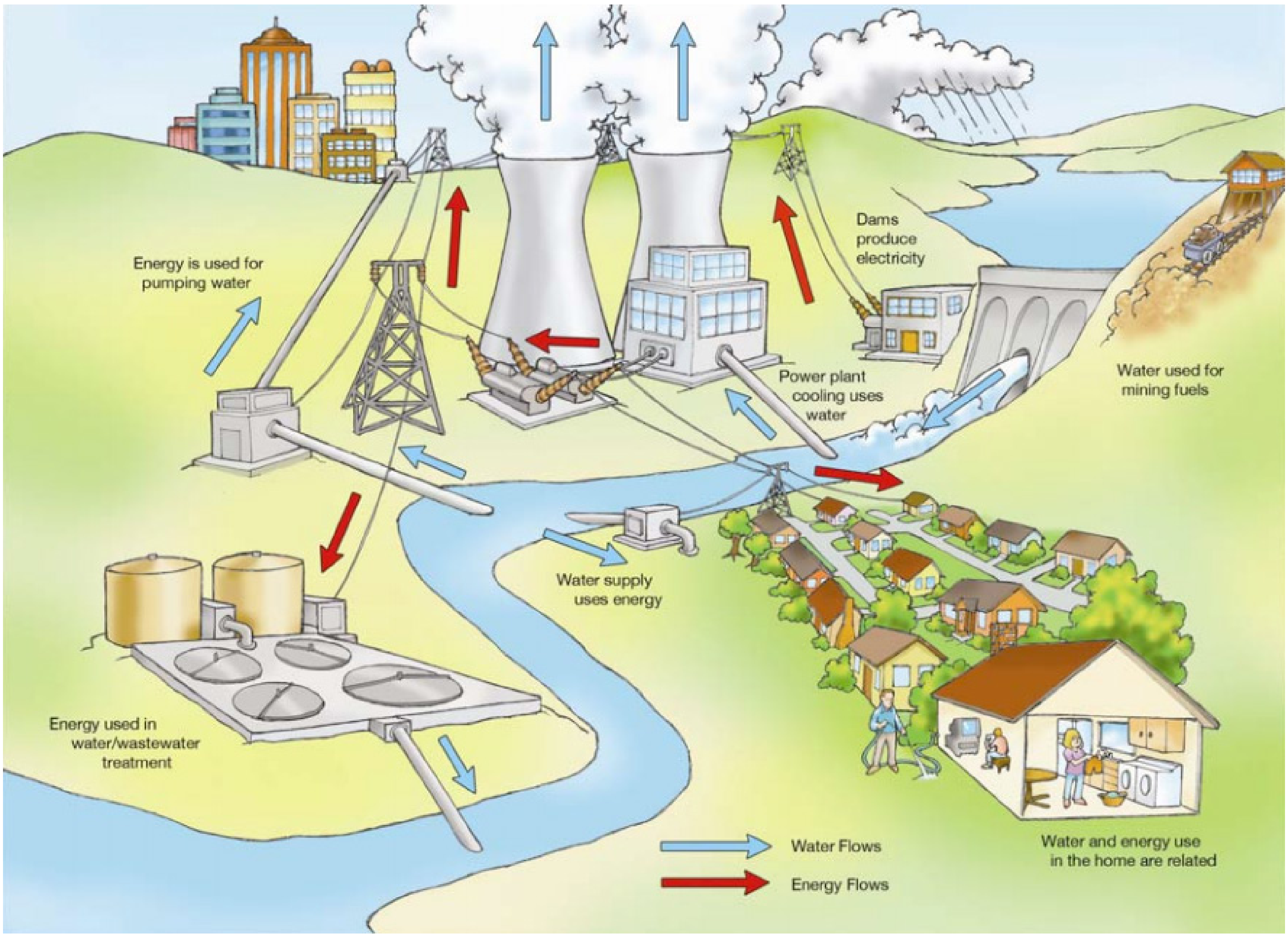
The 2020 Asia Poverty Reduction Report launched at the Boao Forum for Asia (BFA) found that Asia is leading the world on poverty reduction[122]. In the past four decades, China has lifted a total of 770 million rural residents from poverty. This is largely attributable to China's national strategy and targeted measures on poverty reduction, many of which have been enabled by digital technologies such as E-commerce platforms[123].

4.7 Integrated solutions for circular systems

This section introduces the concept of systems thinking and how integrated solutions with embedded circular principles can help improve the overall economic, social and environmental sustainability of complex systems (e.g., infrastructure clusters, industrial zones or urban communities). Instead of focusing on a specific technology application per se, it will discuss opportunities to apply integrated solutions in the design and management of circular systems.

4.7.1 Understanding nexus in a system

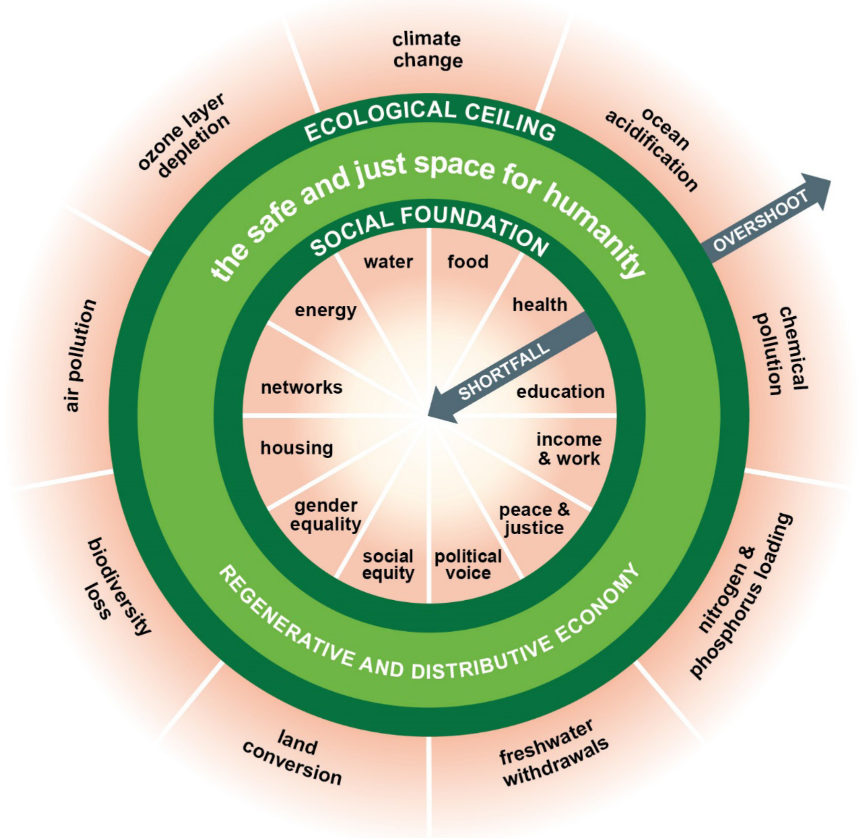
Often, the material and energy flows in a system are analyzed separately for their stand-alone impacts. However, understanding the nexus of various elements in a complex system may help gain new insights. Consider, for example, the water-energy nexus in an urban environment. On the one hand, in order to keep an urban water infrastructure system running, a large amount of energy is required to power processes such as water extraction, transport, treatment, distribution and wastewater treatment. On the other hand, water is used in energy manufacturing for various purposes such as cooling water in the thermal power plants, or generating renewable power through hydrological dams. Synergies also exist in the urban water and energy systems, for example, effluents from a Waste Water Treatment Plant (WWTP) can be used as the influent of a membrane-based facility to produce the purified water for a proximate thermal power plant. The red and blue arrows in **Figure 21** illustrate a water-energy nexus system that is interconnected and interdependent. The strength of one cycle might affect the resilience of the other; for instance, water scarcity may reduce hydroelectric electricity output, which may trigger energy insecurity.



• *Figure 21: A diagram of a water-energy nexus*
Source: US Department of Energy, Energy Demands on Water Resources, 2006[124]

4.7.2 Systems thinking for a circular economy

Emerging economic theories have highlighted, with growing evidence, the interdependency of our economy, society and the environment (biosphere). For the economy to thrive and bring sustained benefits to society, it has to operate within a set of nine planetary boundaries (Rockström et al., 2009)[125]. Further building on the planetary boundary concept, the Doughnut Economy framework (**Figure 22**) points to a central green space between the rings as a safe and just space for humanity and for a regenerative and distributive economy (Raworth 2017)[126]. Although perhaps supporting social and economic functions, overusing Earth's resources and dumping harmful materials into the environment, will result in the overshooting of planetary boundaries.



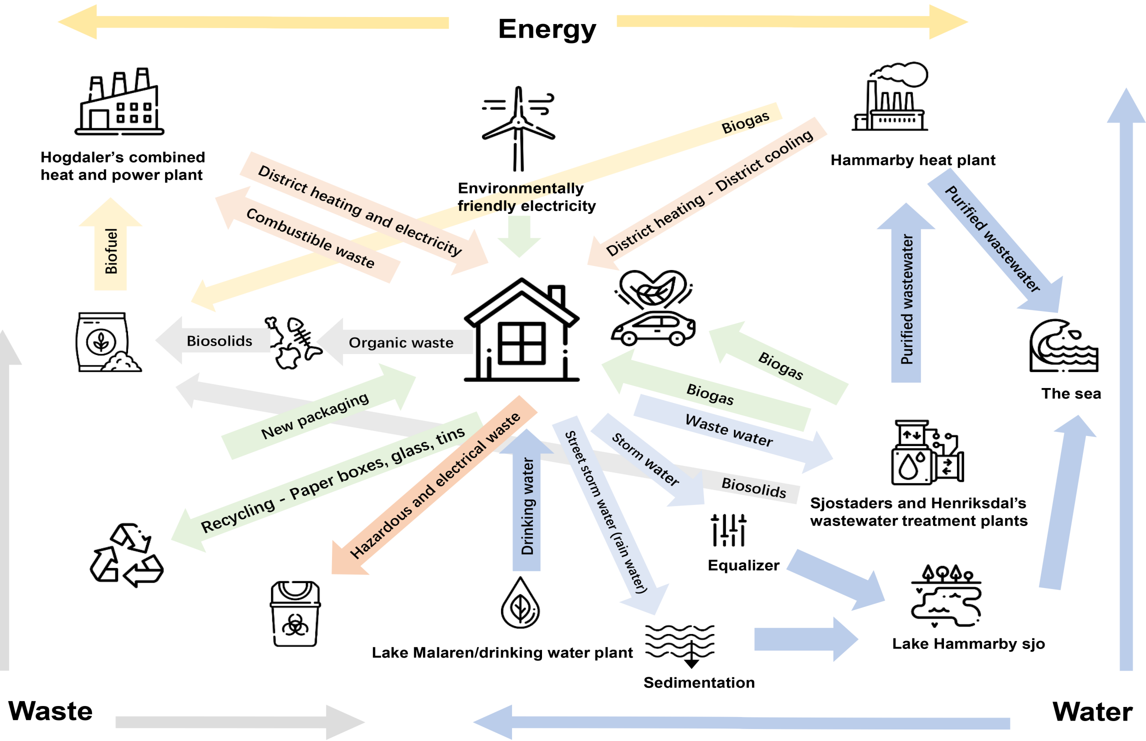
• *Figure 22: The Doughnut economy diagram*
Source: Raworth, 2017[126]

Recognizing the interdependency of the economy, society and environment is crucial for achieving a circular economy that respects planetary boundaries, closes as many linear and wasteful economic loops as possible, expands regenerative exchange with the biosphere and creates additional value for society and the environment as a whole.

Designing circular systems thus requires a good understanding of how different parts of a system interact to product the behavior of the whole – an approach of systems thinking, as defined by the Ellen MacArthur Foundation[127]. A systems thinking approach considers the flows of material, energy and “waste” (potentially a useful input for another process) in an integrated manner, and prioritizes the system effectiveness as a whole, rather than that of an individual stream.

Let’s look at an example of how systems thinking was applied to turn a once wasteland into a world-famous eco-neighborhood.

The Hammarby Sjöstad neighbourhood in Stockholm, Sweden is widely considered as a blueprint (design model) of a circular city. The Hammarby model (**Figure 23**) integrates energy, water and waste management to create a unique ecosystem with closed energy and resource loops within the neighborhood. For example, all the apartments in Hammarby are built with materials that provide maximum insulation during Sweden’s harsh winters, so as to reduce heating-related energy use. Gas and electricity come from renewable sources such as solar power and biogas, partially supplied from the extraction of sewage sludge from the area's wastewater treatment plant. The public transport network includes biogas-powered buses, wide bicycle lanes, a tram line and a free ferry service to reduce car use. In comparison with a typical suburb, Hammarby managed to cut environmental impacts by 50 per cent, while delivering economic success for the community with an increased property value by roughly 25 per cent over time[128, 129].



• *Figure 23: The Hammarby circular model*
Source: Adapted from Figure 7 of Public Procurement for Innovation in Baltic Metropolises (Lember, 2007)[129]

"Hammarby Sjöstad is a good example of not only focusing on the short term aspects and getting short term profits but also investing for the future and increasing revenue. The cost for Hammarby was roughly 5 per cent higher from a purely construction cost perspective but in the end you get back roughly 25 per cent more property value out on the site over time which shows how real value is created over time."

- Henrik Svanqvist, Director of Communities, Skanska (a key developer of Hammarby Sjöstad)[130]

The Hammarby model continues to inspire sustainable urban development projects worldwide, from Toronto and London to many eco-cities and communities in China (Yantai city) and Thailand (Amata Smart City)[131]. Perhaps the biggest take-away from this example is that sustainability is not a privilege only for rich countries, and if circular and sustainable features can be designed and incorporated early on, does not necessarily cost more.

By 2050, two-thirds of the global population, most of which is in Asia and Africa, is projected to be urban[132]. Cities are already responsible for 50% of global waste and 60-80% of global GHG emissions, and are expected to consume more than double the amount of materials by 2050 as in 2021[133, 134]. Given the sheer scale of material and energy consumption associated with urbanization and urban development, city planners need to adopt a systems approach that is integrated rather than sectoral, linking together urbanization and human well-being, while maintaining efficient resource consumption. This may, for example, include introducing smart and connected infrastructure assets for energy efficiency and prolonged asset life, and integrated spatial planning for urban development[135].

Another important application of circular systems is in the form of industrial parks, often represented by a cluster of industrial activities and associated commercial and infrastructure services.

Through shared infrastructure and utility services and waste management, early-day industrial parks efficiently used economic inputs for industrial processes. Later on, the concept of eco-industrial parks was promoted to "ensure sustainability through the integration of social, economic, and environmental quality aspects into its siting, planning, management and operations" (WB UNIDO GIZ 2017)[136].

Eco-industrial parks exemplify the circular economy concept at a local scale. The concept and approach of an eco-industrial park includes many key elements of a circular economy, such as resource efficiency, cleaner production, industrial symbiosis, shared infrastructure, improved spatial zoning and management. All of these aspects involve a systems-thinking that promotes circularity and closes material and waste loops.

Several Asian countries, such as South Korea, Vietnam, China and India, have piloted the creation and operation of eco-industrial parks with success. For example, between 2015 and 2016, the Ulsan Mipo and Onsan Industrial Park in South Korea was able to reduce its energy use by 279,761 tons of oil equivalent and its CO_2 emissions by 665,712 tons of CO_2. The Park also managed to reuse 79,357 tons of water and 40,044 tons of by-products and wastes, thereby saving US$554 million from an original investment of US$520 million in industrial symbiosis, and generating US$91.5 billion in revenue (UNEP 2021)[137, 138].

A green industrial park in Telangana, India has been developed under the support of the Association of Lady Entrepreneurs of India (ALEAP) and GIZ. The site master planning caters to the needs of 170 women entrepreneurs and ensures that a host of economic, social, environmental sustainability and equality issues are addressed. For example, the park is designed to meet green building standards, with efficient circulation systems and eco-friendly building materials. PV roof tops, solar streetlamps, and a solar power plant are included in the site master plan. The pollution control and waste management system allow for recycling and/or reuse of wastewater and waste, and rainwater harvesting, and include a vermi-composting plant for organic waste. Common infrastructure services also include special provisions for women employees, including play schools and crèches for workers' infant children of, ladies' restrooms, and accommodations for late working hours (WB UNIDO GIZ 2017)[136].

4.8 Exercise

(1) Describe some of the sustainability challenges and opportunities in Asia.

(2) Discuss the significance of transitioning towards a circular economy in the context of Asia, and the importance of technology in this transition.

(3) The UN 2030 Agenda for Sustainable Development, comprising of 17 Sustainable Development Goals (SGDs) and 169 targets, provides a useful global framework to guide country efforts towards long-term sustainability in three dimensions – the economy, society and environment. Identify an SDGs and its sub-targets and explain how a circular economy may contribute to the realization of the SDG targets?

(4) We have identified three key sectors – Energy, Water and Waste Management, that are critical for achieving a circular economy in Asia. Please discuss the most relevant sectors in your country that are contributing to unsustainable consumption and production, and which therefore require a shift to a more circular model. Discuss with sectoral-specific data and examples.

(5) Compare and contrast the following technologies for producing renewable energy. Discuss their pros and cons in terms of energy efficiency, cost, storage, compatibility with existing grid and energy infrastructures, and safety etc.
- Solar
- Wind
- Hydro power
- Hydrogen
- Nuclear

(6) Identify technologies that can be applied to reduce food waste in each of the following processes/steps of the food value chain: Farming/Crop harvest, Collection and Storage, Transportation, Food Processing, Food packaging and storage, and Retail distribution/Supply chain management.

(7) Discuss the interlinkages in a water-energy-climate nexus. Explain why the failure of one cycle (e.g climate) could potentially weaken the health of the other two.

(8) Imagine you are a city planner and tasked to redesign the neighbourhood you are currently living in to make it a more circular one. With a systems thinking approach, identify three key strategies to be included in your master plan. (Note: you are free to define the specifics of the neighbourhood you are about to redesign.)

4.9 Learning materials

Energy Efficiency Indicators Highlights (2020 edition), IEA
https://webstore.iea.org/download/direct/4266?fileName=Energy_Efficiency_Indicators_Highlights_2020_PDF.pdf

Energy Efficiency Indicators Database Documentation (2020 edition), IEA
Microsoft Word - Efficiency indicators_Documentation_2020.docx (windows.net)

2006 IPCC Guidelines for National Greenhouse Gas Inventories
Publications - IPCC-TFI (iges.or.jp)

Zerocarbon Humber
Home | Zero Carbon Humber

Supply Chain Entities and their Possible Activities in Food Waste Reduction
FOOD WASTE REDUCTION AS A CHALLENGE IN SUPPLY CHAINS MANAGEMENT (logforum.net)

The Sustainable Development Goals
THE 17 GOALS | Sustainable Development (un.org)

The Sustainable Development Goal Indicators
Home — SDG Indicators (un.org)

Fertigation and Chemigation: Efficient variable-rate fertigation systems
Variable-Rate Fertigation Has Emerged (agriculture.com)

Digital Agriculture
Digital technologies in agriculture and rural areas - Briefing paper (fao.org)

Greenhouse Gases from wastewater treatment – A review of modelling tools
Greenhouse gases from wastewater treatment — A review of modelling tools - ScienceDirect

Quantifying the greenhouse gas emissions of wastewater treatment plants
https://edepot.wur.nl/138115

Emissions estimation for IPCC 2006 Guidelines Compliance in the UK Waste Sector
DECC report (defra.gov.uk)

Main Linkages within the land, water and energy nexus
https://knowledge.unccd.int/publications/land-water-energy-nexus-biophysical-and-economic-consequences

An urban development case study of Hammarby Sjostad in Stockholm, Sweden
https://energyinnovation.org/wp-content/uploads/2015/12/Hammarby-Sjostad.pdf

A collection of Circular Economy success cases. Ellen MacArthur Foundation
https://ellenmacarthurfoundation.org/circular-example-collection

European Circular Economy Stakeholder Platform: Circular Economy Good practices in the EU
https://circulareconomy.europa.eu/platform/good-practices

Unit 5: Looking Forward

5.1 Context

The COVID-19 pandemic has severely impacted the global economy, disrupted supply chains, affected the livelihood of the millions and driven many to re-think how they want to live, work and connect with others. As governments around the world prepare to commit trillions of dollars in stimulus programs, the call for a green recovery that can pave the way for a resilient and low-carbon future is growing.

By redesigning our economic system to be waste-free, effective and regenerative, circular economy presents a vital opportunity for post-pandemic recovery. Technological innovations, designed to digitalize and decarbonize our production and consumption patterns, can play a key role in realizing this vision at scale. Policy makers should consider putting in place an enabling policy framework to incentivize the investment and adoption of circular technologies.

Even before the pandemic, the fourth industrial revolution (4IR) – characterized by disruptive digital technologies such as Artificial Intelligence- has been rapidly unfolding. However, the mass deployment of disruptive technologies may bring unintended consequences on social justice and inequality. Thus, to ensure a transition that leaves no one behind, special attention in policy design is required.

5.2 Learning objectives

After completing this Unit, participants will be able to:

- Identify key technology trends for a circular economy;
- Outline 3 enabling policy conditions for promoting circular technology innovation and diffusion;
- Explain concerns of social justice and equality surrounding the mass deployment of disruptive technologies, and discuss key considerations to ensure a just and inclusive transition to a circular economy.

5.3 Technology trends for a circular economy

Since the industrial revolution, our global economy has been largely powered by the use of natural resources. As Dr. Schwab of the World Economic Forum has famously described it.

> *"The First Industrial Revolution harnessed water and steam power to mechanize production. The Second used electricity (generated by non-renewable fossil fuels) to create mass production. The Third used electronics and information technology to automate production. Now a Fourth Industrial Revolution is building on the Third... characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres" (Schwab 2017; Lacy and Rutqvist 2016)*[139, 140].

A shift to a circular economy calls for transformative technologies that will reshape global consumption and production patterns. Digitalization and decarbonization are two key technology trends for a circular future. The former enables millions of producers and consumers to design and adopt circular business models at scale, and the latter allows for the mass generation and use of energy from renewable sources, thus fundamentally shifting away from an unsustainable, linear economic pattern.

5.3.1 Digitization

Today, billions of people are already connected by mobile devices. Digitization is increasingly shaping the way we live, work and connect with each other. With the fourth industrial revolution (4IR) on the horizon, emerging disruptive technologies, such as Artificial Intelligence, Big data analytics, cloud computing and 3D printing, present new possibilities for reimagining how we design, build and consume materials and resources.

In their book Waste to Wealth, Lacy and Rutqvist discuss ten disruptive technologies that are likely to transform the economic system into a circular economy (Lacy and Rutqvist 2016)[140]. Those technologies can be grouped into three broad categories: digital technology, engineering technology, and a combination of these two (hybrid technologies), such as machine to machine communication, 3D printing and advanced recycling technology.

Take Artificial Intelligence as an example. A study conducted by Google and the Ellen MacArthur Foundation found that AI can enhance and enable circular economy innovation across industries in three major ways (EMF 2019)[71]:

- **Designing circular products, components, and materials.** For instance, iterative machine-learning-assisted design processes can facilitate new material innovation by rapid prototyping and testing.
- **Operating circular business models.** Empowered by big data analytics, AI can enhance business competitiveness for many circular models, such as product-as-a-service (PaaS). For example, to reduce food waste, restaurants, retailers and other hospitality institutions are using AI algorithms to forecast and predict sales, in order to more effectively connect the supply and demand of food orders.
- **Optimizing circular infrastructure.** Circular models seek to create closed loops in the business-user interface by promoting "repair, refurbish, remanufacture, repurpose and recycle" – all of which rely on the efficient reverse logistics infrastructure that AI can help build and improve. One such example is the advanced recycling system, which deploys visual recognition techniques (cameras and sensors) to sort mixed waste streams that include wastes ranging from plastic packaging to construction waste.

Digital technology and other innovative technologies can transform the way we design, build and operate infrastructure assets and enhance value. Engineers, designers, and architects are combining computational design, materials engineering and 3D printing technology to transform conventional construction into "a modular process", saving materials and making disassembly and material recovery possible. Repair is also made easier by 3D printing building modules and components.

However, integrating digital solutions for a circular economy remains challenging in some parts of the Asia region, owing in part to the poor infrastructure systems, as well as key regulatory and market barriers, such as low consumer awareness and weak business case for building digital infrastructure, and limited supply of local content as a result of a weak local digital ecosystem (ASEAN-ERIA 2018)[141]. To overcome these barriers, policymakers would provide an enabling policy framework to stimulate market activities and leverage public and private financing to foster a local digital ecosystem.

5.3.2 Decarbonization

Our world is already 1.1 degrees warmer since pre-industrial times (UNEP 2019)[142]. According to the International Energy Agency, getting back on track towards a world well below 2-degrees, and to reach net-zero emissions by 2050 requires decarbonization of the global energy system and the mass deployment and innovation of clean technologies, such as solar and wind power generation, advanced batteries, hydrogen electrolysers and direct carbon capture, utilization and storage (CCUS). However, the rapid scaling of clean energy technologies is expected to create a significant growth in demand of critical minerals required for those technologies – by one estimate, demand for lithium for use in batteries is likely to grow thirty-fold to 2030 and is more than 100-times higher in 2050 than in 2020 (IEA 2021)[143]. Such exponential growth of critical materials vital to the clean energy sector, such as lithium, cobalt and nickel, has led to a rising concern over the security of material supply in the long run, and has incentivized the industry to adopt circular business models to close the material loop (Zeng and Li 2021)[4]. For example, the battery recyclers and researchers are working together with manufacturers of EV batteries to develop a circular battery supply chain, with a circular design of recycling in mind[144].

Closing the circularity gap of resource extraction presents great synergy to climate mitigation efforts. The IEA predicts that, through improvements in material efficiency and increased recycling, industrial carbon emissions are expected to decrease by around 40% in 2030. Material efficiency alone, as a result of improved design and construction of buildings and vehicles for quality and durability, can reduce the global demand for cement and steel by 20%, saving around 1700 Mt CO_2 (IEA 2021)[143]. Increased industrial reuse and recycling for carbon-intensive materials such as steel and cement may contribute to significant energy and material efficiency gains. For example, steel products reaching their end-of-life can be reused in scrap-based production, which uses only around one-tenth of the energy needed in primary steel production.

Between 2020 and 2050, about 80 per cent of the global new building construction is planned in developing countries. The region of Asia, as the frontier of global urbanization and industrialization, is expected to attract a significant portion of infrastructure investment in the post-Covid stimulus effort. In this context, Asia's developing countries and emerging markets hold great potential for generating and piloting the future technologies for a circular economy, while delivering on significant emission reduction results. By one estimate, a 50 per cent reduction of cement and steel use in the building and construction sector can be achieved by incorporating circular measures at design, construction, use and end-of-life phases by 2050 (IEA 2021)[143].

Trends in digitalization and decarbonization have never been more important in circular economy policymaking. However, the mass deployment of disruptive technologies and the rapid decarbonization in energy-intensive sectors may bring uneven impacts to the people and communities, particularly in low- and middle-income countries. For instance, during the transition to a circular economy, some resource-intensive and extractive-oriented sectors may see adverse impacts on employment and revenue in the short run. The emergence of digital circular models (i.e., sharing platform) may not only bring productivity improvements and resource optimization to society at large, but also lead to concentrating market dynamics and potentially worsening economic security for certain workforce employed under insufficient social security coverage (Schroder 2020)[145]. Thus, special considerations in policy designs and targeted assistance programmes at national, regional and local levels, are required to address these challenges and ensure a transition that is just and inclusive for all.

5.4 The policy perspective

Realizing a circular economy will require societal-wide transformation in the ways we produce and consume. This calls for a concerted effort among policymakers, scientists and researchers, and the business community to foster innovation and to bolster pilot and large-scale adoption of new technologies and circular business models. While many of the critical technologies for transition to a circular economy are already available, rapid scaling of technologies to reach commercial successes relies heavily on the creation of enabling policy and institutional conditions (e.g., through the promotion of public-private partnerships). By setting circular design standards and regulations, providing incentives and setting targets to extend product and building lifetimes, and investing in future-proof circular infrastructure systems (such as improving the waste material collection, sorting and recycling infrastructure), governments can lay the foundation for unlocking massive investments needed to accelerate clean technology diffusion at scale.

The COVID-19 pandemic reflects humankind's vulnerability in pursuing the unlimited exploitation of nature. As world leaders discuss post-pandemic recovery packages, the call for a system-wide shift to a resilient, climate-neutral and resource-efficient economy is ever growing. The European Commission, for instance, has announced a new Circular Economy Action Plan aimed at promoting "a regenerative growth model that gives back to the planet more than it takes" and reducing "its consumption footprint and double its circular material use rate in the coming decade".

However, an Oxford study finds that the economic stimulus packages implemented by G20 countries so far comprise of more 'rescue' than 'recovery' polices, which focus on short-term livelihood reliefs. Only 4% of the announced polices are considered "green", with long-term climate benefits[146].

To promote long-term competitiveness and the transition to a circular economy, it is imperative for governments around the world to consider policies aligned with circular principles in their recovery packages. These include:

- **Adopting green fiscal measures to support circular business models by reducing taxes** (such as value added taxes) on reuse, repair, remanufacturing and recycling activities, and regenerative food production (EMF 2021)[147]. This will also incentivise circular designs, which help to keep the value of goods, materials, and nutrients in circulation for as long as possible. For example, the EU Circular Economy Action Plan encourages Member States to use differentiated value added tax rates to promote circular economy activities that target final consumers, notably repair services.
- **Removing fiscal subsidies on fossil fuels and introducing market-based mechanisms to put a price on carbon externalities**. This will help align the price signals of non-renewables and renewables as industrial inputs and drive investment and innovations towards a low-carbon and resource-efficient production pattern.

- **Incorporating circularity criteria into sustainable public procurement schemes**. Even before the pandemic, public procurement funding accounted for a sizable portion of many countries' gross domestic product – for many developing countries the percentage was as high as 30% (UNEP 2018)[148].The massive stimulus packages now offer an unprecedented opportunity to create demand in sustainable products and services, and to unlock investments in R&D for green technologies. Sustainable public procurement practices may include, for example, setting mandatory targets for public tenders to use recycled and low-carbon materials, and favouring the design and construction of buildings and public infrastructure that meet circular standards. The city of Amsterdam, for instance, has developed a roadmap for Circular Land Tendering that includes 32 performance-based indicators for circular building development (EMF 2021)[147].
- **Promoting integrated infrastructure planning for a circular economy.** The trillion-dollars worth of recovery packages will likely boost a new round of infrastructure development. As infrastructure is typically designed for decade-long lifespans, it is critical that stimulus investments go into sustainable infrastructure that is planned, built and operated with integrated circularity features. Applying systems thinking can help maximize synergies across different infrastructure systems and sectors, close resource and material loops and enable industrial symbiosis. For instance, the density of infrastructure provisions in large cities presents a great opportunity for integrated spatial planning and circular infrastructure designs that incorporate waste-to-energy facilities or district heating systems (UNEP 2021)[138].
- **Fostering local value chains by supporting local businesses, particularly small and medium-sized enterprises (SMEs).** While the global supply chain has experienced major disruption during the pandemic, it is important for recovery efforts to focus on rebuilding economic resilience through supporting local SMEs and fostering local value chains with shorter/closed material loops and lower material and carbon footprints. In this regard, public schemes could offer incentives to local businesses to incorporate circular design principles and business models, and leverage digital technologies to improve their competitiveness and environmental performance, and strengthen their resilience against future shocks.

5.5 Exercise

(1) Your country's government has just published a post-pandemic stimulus strategy that comes with a massive investment plan in the economy and livelihood relief. You are invited to participate in a consultation process as the youth representative. What suggestions would you give to your government to enhance the policy design and implementation of this Covid-recovery plan to ensure a just and green transition to a circular economy?

(2) a) Are you in favor of the mass deployment of disruptive digital technologies such as AI, IoTs and blockchain in our economy? Why?

b) If not, what do you think need to be put in place to mitigate the negative impacts of wider application of disruptive technologies?

(3) You are asked to develop a national roadmap for sustainable infrastructure development in your country (2021-2030). Identify the potential benefits of incorporating circular economy principles into the infrastructure planning processes.

(4) How can technologies such as AI support the decarbonization of the economy?

(5) Describe the relationship between improvements in material efficiency and climate change mitigation.

5.6 Learning materials

The circular economy: a transformative COVID-19 recovery strategy. The Ellen MacArthur Foundation.
https://www.ellenmacarthurfoundation.org/assets/downloads/The-circular-economy-a-transformative-Covid19-recovery-strategy.pdf

Delivering the circular economy – A Toolkit for Policymakers. The Ellen MacArthur Foundation.
https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_PolicymakerToolkit.pdf

Promoting a just transition to an inclusive circular economy. Patrick Schroder, Chatham House
https://www.chathamhouse.org/2020/04/promoting-just-transition-inclusive-circular-economy-0/about-author

Frontier Technology Quarterly: Does the sharing economy share or concentrate? UN DESA, 2020.
https://www.un.org/development/desa/dpad/publication/frontier-technology-quarterly-does-the-sharing-economy-share-or-concentrate/

Industrial 4.0: Empowering ASEAN for the Circular Economy. Venkatachalam Anbumozhi and Fukunari Kimura (Ed.). Economic Research Institute for ASEAN and East Asia.
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