ELLEN MACARTHUR FOUNDATION

清華大學环境学院
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THE CIRCULAR ECONOMY: A ‘TRIPLE PLAY’ SOLUTION FOR ACHIEVING CHINA’S CLIMATE OBJECTIVES

Contents

About this paper

This study highlights the fundamental benefits of the circular economy for climate action in China. It aims to detail the specific role of circular economy interventions in sectors that shape daily life — i.e., residential buildings, mobility, and plastics. It also shows how the circular economy will be crucial to successfully managing the fast expansion of new — and decommissioning of old — renewable energy infrastructure in China, while helping increase the resilience of the economy to the effects of climate change. This study sets out actions policymakers can take to achieve this shift.

Developed jointly with Tsinghua University, this study presents the theoretical underpinnings of how the circular economy is essential for tackling climate change, however rigorous quantitative analyses will be needed to get a fuller understanding of its potential. This paper is part of the Ellen MacArthur Foundation’s ongoing research into circular economy opportunities in China and draws on insights from the Foundation’s previous research reports, including Building Prosperity: Unlocking the potential of a nature-positive circular economy for Europe (2024); *Completing the Picture: How the circular economy tackles climate change* (2019); and *and Universal Circular Economy Policy Goals (2021).*

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About the Ellen MacArthur Foundation

The Ellen MacArthur Foundation is an international charity that develops and promotes the circular economy in order to tackle some of the biggest challenges of our time: biodiversity loss, climate change, and waste and pollution. We work with our Network of private and public sector decision makers, as well as academia, to build capacity, explore collaborative opportunities, and design and develop circular economy initiatives and solutions. Increasingly based on renewable energy, a circular economy is driven by design to eliminate waste, circulate products and materials, and regenerate nature, to create resilience and prosperity for business, the environment, and society.

Further information:
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About the Tsinghua University Research Center for Industry of Circular Economy

The Tsinghua University Research Center for Industry of Circular Economy (CICE) was founded in 2009 by the superior team of the School of Environment, Tsinghua University. CICE is committed to scientific research in the field of solid waste recycling, circular economy, energy conservation and emission reduction management, joint research on key technologies and applications, supporting the national policy formulation of circular economy and zero-waste cities and carrying out international cooperation on systematic solutions for circular economy. CICE has completed nearly 100 national, provincial and ministerial research projects such as the National Key Research and Development Program, 863 Plan, 973 Plan and the National Natural Science Found Program, and more than 200 consulting projects for local governments, industrial parks, and enterprises. CICE has won nearly 10 honors such as the second prize of the National Science and Technology Progress Award and the first prize of Ministerial and Provincial-Level Science and Technology Progress Award, providing scientific and technological support for the development of circular economy and promoting carbon emission reduction.

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Executive Summary

At the heart of China's vision of economic transformation — from rapid growth to high-quality development — sits the 'dual carbon' targets: to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. To help achieve these targets, China continues its fast build-out of renewable energy infrastructure, maintaining its position as the primary contributor to the global expansion of renewable power generation capacity. In parallel, the country is rapidly transitioning into a consumption- and service-based economy, and is transforming its industrial sector to focus on advanced technology and high-value manufacturing.

In this context, China's adoption of a comprehensive circular economy framework can play a pivotal role in achieving both its climate and broader economic goals. **This paper sets out how the circular economy offers a 'triple play' solution for achieving climate objectives: reducing greenhouse gas (GHG) emissions in hard-to-abate sectors, helping secure critical raw material supply in the transition to renewable energy, and enhancing resilience across the economy against the effects of climate change.** The report identifies five areas for policy action to catalyse this transformation and thereby help foster a harmonious relationship between economic growth and environmental regeneration.

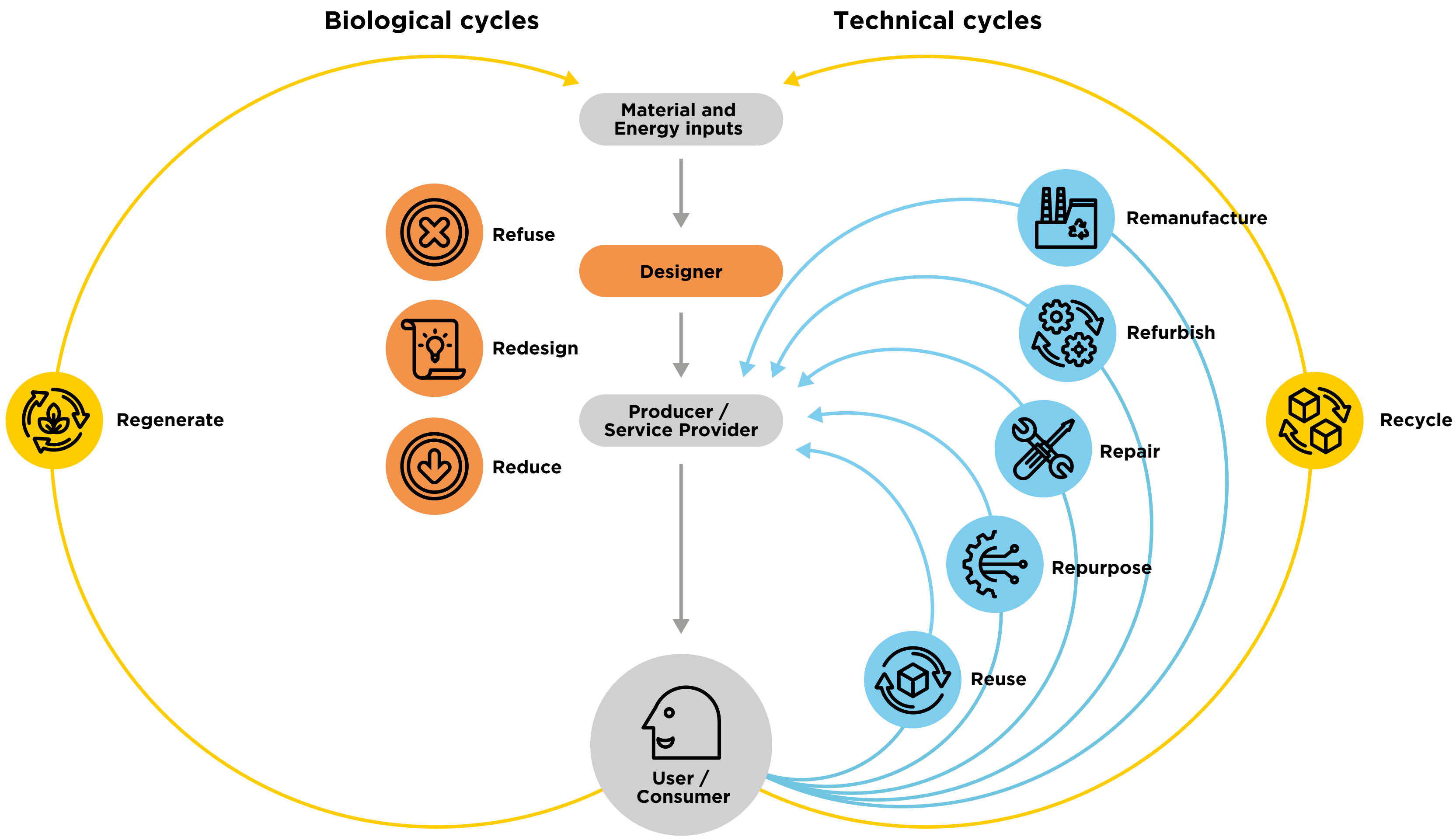
A comprehensive approach to circular economy allows China to build on its pioneer status to reap greater economic and environmental benefits

China has deep roots in circular economy practices, from ancient agricultural systems to recent industrial policies. Over the past two decades, China has implemented targeted circular economy strategies, including cleaner production techniques, industrial symbiosis, and robust recycling systems.

The 3R strategy — reduce, reuse, recycle — has been effective, but is insufficient to address deeper environmental issues and economic losses. This paper emphasises that the circular economy is not solely about waste management: at its heart it is about designing higher-value patterns of production and consumption.

Expanding from 3R to 10R will embed upstream interventions — including redesign, repair, and remanufacturing — into business practices and policy frameworks. This comprehensive approach is instrumental to creating a regenerative economy that systematically eliminates waste and reduces resource consumption.

The 10R circular economy interventions



1. Reducing greenhouse gas emissions in hard-to-abate sectors

In China, the potential of the circular economy is particularly notable in hard-to-abate sectors that shape daily life. Recent estimates highlighted substantial emission reduction opportunities in residential buildings, mobility, and plastics, which together currently account for approximately 4.8 billion tonnes of CO_2e emissions annually. Initial estimates drawn from a review of the literature are that implementing a comprehensive suite of circular economy interventions — spanning production, use phase, and after use — across these sectors could achieve annual emissions reductions of 1.8 billion tonnes, representing over one-third of the total emissions of these sectors. While these sectors do not provide a comprehensive view of all consumption-related emissions in China, they are essential to meeting the needs of its rapidly urbanising and increasingly affluent population, and play a substantial role in the country's evolving emissions profile.

Emission reduction opportunities in high-carbon sectors include:

Residential buildings

China's building model has shifted from meeting basic needs to enhancing building performance and functionality. This demand for reconstruction, alongside continuing urbanisation, has meant China's building sector was responsible for GHG emissions amounting to 3.7 billion tonnes of CO_2e in 2020. However, it is now seeing efforts to integrate circular economy practices, which include:

- **Making the most of existing building stock** can substantially reduce carbon emissions across the building sector. Refurbishing and retrofitting existing structures also reduces costs and resource use compared to building new.
- **Compact city design and regenerating nature in urban areas** help prevent urban sprawl and can increase resilience to extreme weather events by reducing peak temperatures and increasing water permeability.
- **Modular design and prefabricated buildings** are rapidly developing in China and are already reducing embodied emissions due to their material and energy efficiency and their increasing use of low-carbon building materials.

Mobility

Despite a fast-growing penetration of electric vehicles (EVs), the passenger vehicle sector in China was responsible for life-cycle emissions of 0.7 billion tonnes of CO_2e in 2020. Circular economy strategies for the mobility system as a whole, as well as for the material aspects of vehicle design and use, offer substantial opportunities to reduce emissions:

- **Providing digitally-enabled, on-demand, multi-modal transport**. Integrating zero-emission public transport with shared and private vehicles, supported by a digital platform that enables trip planning and a single-payment solution, provides a convenient experience for users.
- **Scaling up ride sharing**. Ride-sharing, a consumer-to-consumer (C2C) shared mobility method, increases seat utilisation and reduces emissions, the number of vehicles on the road, and traffic congestion.
- **Increasing automotive parts remanufacturing** is key to reducing embodied emissions in vehicles. Prioritising major components like engines and steering systems substantially reduces emissions compared to manufacturing new.

Plastics

China's plastic sector faces challenges related not only to waste and pollution but also to GHG emissions. The Chinese plastic sector emitted 0.4 billion tonnes of CO_2e in 2020 throughout its value chain, of which production and manufacturing accounted for 85%. Circular economy interventions focus on upstream solutions to these challenges:

- **Prohibiting the production and use of problematic single-use plastics** such as single-use straws, sticks, and cutlery. This is a critical step towards advancing a circular economy for plastics and has already begun in China.
- **Redesigning plastic products to be reusable, recyclable, and made from renewable materials** is key to reducing demand for carbon-intense virgin plastic production and therefore to reducing emissions.
- **Reusing plastic products** is a tangible way to reduce emissions. In the case of plastic packaging, business-to-consumer (B2C) models include refill solutions and reusing packaging involved in, for example, home food delivery.

2. Helping secure critical raw material supply in the transition to renewable energy

The fast-growing wind and solar sectors in China increase the country's exposure to the supply risks associated with imported critical raw materials. Between 2010 and 2023, China's installed capacity of renewable electricity generation increased by 1,000 GW and is projected to increase by a further 3,300 between 2023 and 2050. For critical raw materials in these supply chains — such as zinc, copper, and silver, — China relies heavily on imports, which are subject to supply risks.

China is at the beginning of a mass decommissioning of wind and solar infrastructure, but downstream solutions dominate. By 2050, it is projected that China will generate up to 23 million tonnes of discarded wind turbine blades and up to 88 million tonnes of discarded solar panels cumulatively. Much of this waste is currently burnt or landfilled and circularity efforts have to date focused mainly on downstream solutions such as downcycling. Designing-in upstream opportunities will be crucial in the next phase of scale-up.

3. Enhancing resilience across the economy against the effects of climate change

- **Supply chain resilience can be increased by circular economy practices**. By designing products that can be reused, repurposed or remanufactured, businesses can reduce their dependence on raw materials and mitigate the risks of supply chain disruptions, including those caused by the impacts of climate change.
- **A good example is China's renewable energy sector, which relies on critical raw materials like copper, zinc, and rare earth elements.** Circular strategies can reduce China's dependence on imports by reusing materials from decommissioned products such as wind turbines and solar panels.
- **Circular economy initiatives also enhance the resilience of the economy in urban and rural areas**. Integrating nature into urban design (e.g. expanding tree canopies and permeable surfaces) and employing regenerative agriculture practices can help buffer against climate-related disruptions, such as extreme weather events.

Upstream circular economy opportunities to help secure material supplies in China's wind and solar value chains:

- **Designing renewable energy farms for circularity** can yield significant economic and environmental benefits throughout their lifecycle. Opportunities include strategic site selection and regenerative land-use practices.
- **Modular designs and low-carbon materials** can reduce emissions at the production phase by enabling local replacement of components, thereby reducing material consumption and the associated upstream emissions.
- **Maintenance, refurbishment, and remanufacturing** during the use phase are pivotal to extending the service life of products and components and therefore generating maximum revenue from their embedded materials.

Policymakers can help realise these benefits by integrating circular economy into the climate agenda across sectors

China is uniquely positioned to spearhead the transition toward an economic transformation of production and consumption models. Leveraging the Universal Policy Goals framework from the Ellen MacArthur Foundation, this paper outlines a targeted set of actions tailored to China that can catalyse the integration of the circular economy framework into the climate agenda.

Policymakers can take steps in five areas:

Stimulate design for the circular economy

- **Develop circular product-specific policies:** Legislation mandating the integration of circular principles into product design is essential, and priority must be given to material-efficient design and the use of low-impact materials. Material substitution should also be supported through product standards.
- **Promote circular urban planning:** City planners can embed circular economy principles into urban planning of new and existing cities. City-level initiatives on waste reduction and urban mining, which reclaims valuable materials from urban waste, are essential pillars of a circular transition.
- **Redesign renewable energy supply chains:** Land allocation for wind and solar installations should ensure ecological and agricultural interests are not compromised. The government should strategically promote models such as 'Wind+' and 'Solar+', which integrate with other land-use practices.

Manage resources to preserve value

- **Reshape consumption patterns to adopt circular behaviours:** Societal wealth and well-being should be measured with reference to traditional Chinese values such as 'xiaokang', which emphasise spiritual fulfilment and sufficiency. Governments can provide consumers with information about product circularity to raise awareness.
- **Implement mandatory fee-based Extended Producer Responsibility (EPR) schemes:** These are crucial to delivering sufficient funding to cover the net cost associated with managing discarded products. A two-step approach of legislation and an implementation catalogue would be ideal.
- **Harmonise waste management legislation:** Ensuring the Circular Economy Promotion Law clearly follows the 10R framework set out in this paper, combined with sector-specific regulations, could set resource classifications that enable activities related to repair, reuse, remanufacture, and recycling.

Make the economics work

- **Align taxation with circular economy outcomes:** Shifting taxes from renewable resources to non-renewable resource consumption is a key step. Potential measures include a landfill tax, exempting reuse and repair from value-added tax, and awarding carbon credits for circular models.
- **Leverage public procurement to create demand for circular economy initiatives:** A comprehensive circular procurement system would include consistently updating procurement guidelines that prioritise the use of products that meet circular criteria.
- **Support Micro-, Small-, and Medium-sized Enterprises (MSMEs) and informal sectors in the circular transition:** Policy interventions could focus on boosting industrial clusters to enable MSMEs to form eco-industrial networks where the waste or by-products of one company serve as the raw materials for another.

Policymakers can take steps in five areas:

Invest in innovation, infrastructure, and skills

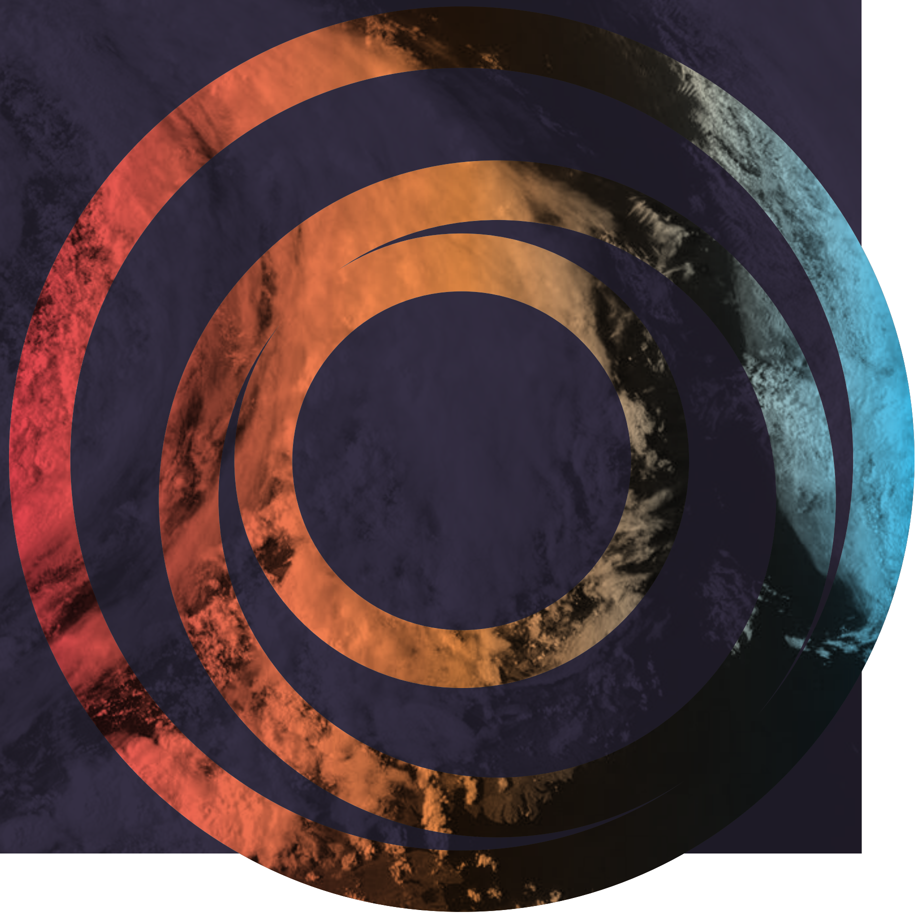
- **Fund circular economy research, development, and innovation:** Prioritise funding for technologies that maximise resource utilisation, leverage digital tools to improve resource management, and support key decarbonisation technologies in material science such as bio-based composites.
- **Invest in circular economy infrastructure:** Prioritise the development of digital sharing platforms, repair and refurbishment centres, and logistics facilities that support key sectors. Incentivise public-private partnerships through co-funding and direct investments.
- **Build a strong circular economy reporting and measurement system:** Establish a vision of the circular economy's scope and develop a comprehensive indicator system. Then set targets for resource productivity and introduce waste reduction goals directly linked to emission reductions.

Collaborate for systems change

- **Stimulate cross-value chain collaboration through eco-industrial parks:** Industrial parks provide a strong foundation for cross-value chain collaboration, with several already serving as good examples. China can scale up these practices by leveraging existing pilot initiatives
- **Engage in collaborative research on the potential for the circular economy to tackle climate mitigation and adaptation simultaneously:** By fostering research partnerships among government, academia, and industry, China can generate data on how circular practices can reduce emissions while enhancing climate resilience.
- **Promote international cooperation:** On the bilateral front, China could focus on leveraging existing agreements with the EU and the US. On the multilateral front, China could drive progress through its Belt and Road Initiative (BRI) and in international forums such as the G20 and the United Nations Framework Convention on Climate Change, in particular by championing the submission before COP30 of enhanced Nationally Determined Contributions (NDCs) that integrate the circular economy as a solutions framework for climate change.

Chapter 1

The circular economy is a systems framework for accelerated climate action in China



Chapter 1

The circular economy is a systems framework for accelerated climate action in China

Climate change stands as one of the most significant challenges facing humanity today. In the journey towards net zero, the circular economy has emerged as a critical strategy, garnering widespread attention.

1.1 The circular economy has a long history in China

Circular economy practices are diverse and have deep historical roots. Ancient China provides early examples of circular economy practices. The Zhou Dynasty's 'Four Seasons Ban' protected natural resources by regulating deforestation and hunting. The 'Mulberry-dyke Fish Pond' agricultural model in southern China integrated mulberry cultivation and fish farming in a circular system. These historical precedents highlight a longstanding commitment to restorative and regenerative production, a fundamental pillar of the circularity concept. However, it was not until the 1980s that the circular economy gained greater recognition and promotion through national legal and policy frameworks, with Germany and Japan being early adopters, focusing primarily on recycling and waste management.

Over the past two decades, the circular economy model has gained significant traction in China via two distinct strategies. First, the principles of the circular economy have been implemented through the 3R framework — reduce, reuse, and recycle — forming the backbone of circular economy practice in China. Second, the implementation of the circular economy has been at three levels: at the enterprise level, emphasising cleaner production techniques; at the regional level, focusing on industrial symbiosis and eco-industrial parks; and at the societal level, establishing robust recycling systems for mainly domestic waste.

To date, circular economy efforts and achievements in China have been primarily concentrated on enterprises and eco-industrial parks. Multi-level policies are typically developed and implemented through a top-down approach, starting from the central government and cascading down to provinces, cities, and then to factories. This process involves setting targets, creating industry-specific indicators, and experimenting with pilot projects. A pivotal strategy in China's circular economy rollout has been the development of industrial symbiosis and eco-industrial parks, which promote resource sharing and by-product exchanges among enterprises and along supply chains. Efforts at the societal level are beginning to take shape, such as promoting circular packaging for e-commerce and launching a recent initiative to drive large-scale equipment upgrades and consumer goods trade-in programmes, although this potential remains largely untapped.

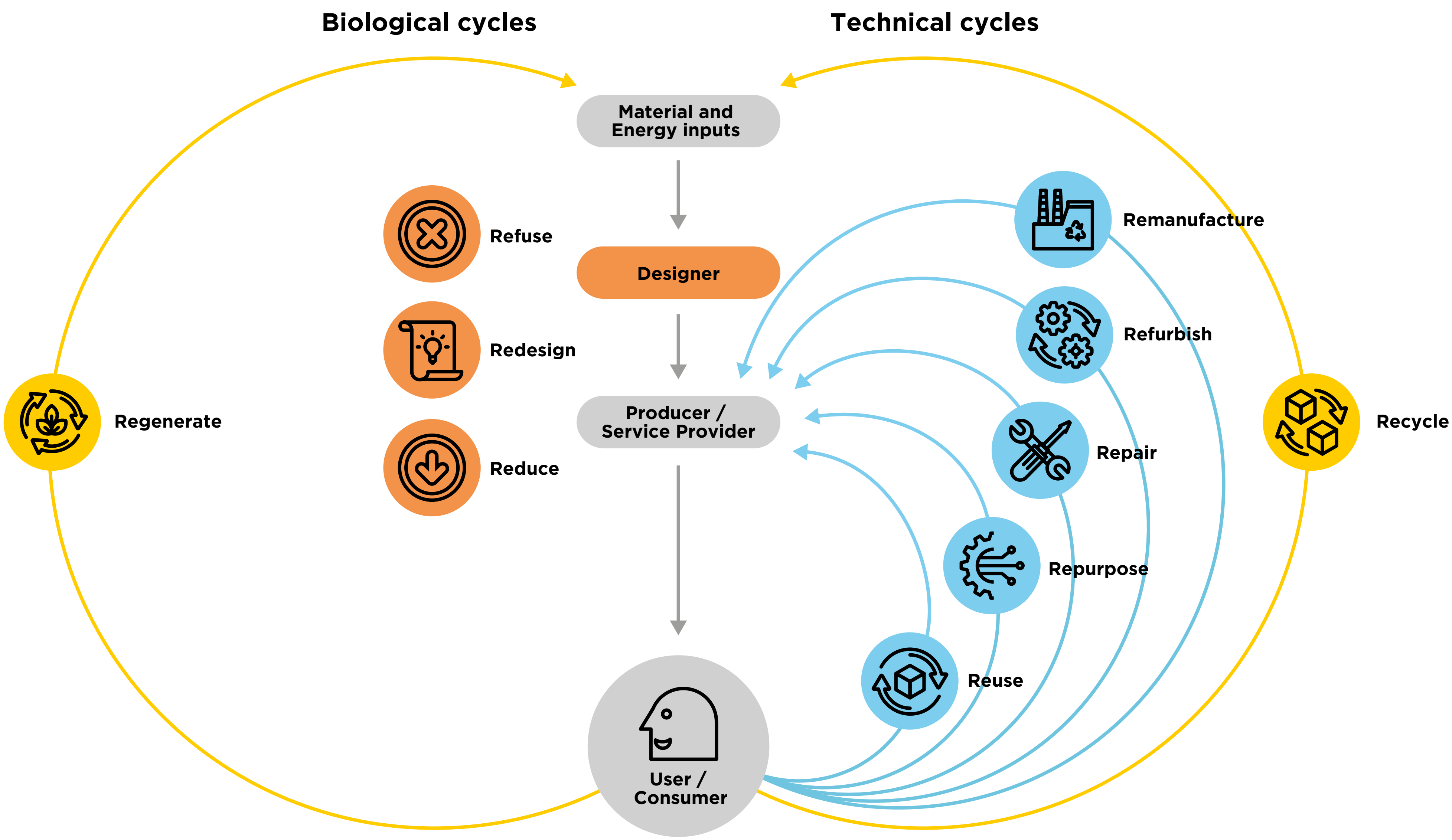
1.2 The conditions for the circular economy in China to expand from 3R to 10R are now in place

The traditional 3R principles, while foundational to China's circular economy efforts to date, fall short in addressing the root causes of environmental degradation and economic losses. These strategies focus on limiting harm ('being less bad') rather than creating a positive impact ('being good').[1] The primary issue lies in their focus on waste management rather than upstream interventions such as product design and shifting consumption patterns. Much of China's 3R strategy emphasises recycling, which often results in downcycling, a process where materials are recycled in ways that reduce their quality and value.

Thanks to technological advancements and innovative business models, it is now possible to prioritise upstream interventions in the material loops of the economy. The advent of digital technologies — such as the Internet of Things (IoT), cloud computing, block chain, and Artificial Intelligence (AI) — and emerging business models, such as Product-as-a-Service and the sharing economy, are driving the expansion of the circular economy in ways that enable higher value circular pathways throughout the production, use, and after-use phases. This represents a shift from 3R to 10R[2,3] (see Figure 1-1) and therefore to a more systems-level interpretation of the circular economy framework. The ten pathways are: refuse, redesign, and reduce (in the design phase); reuse, repurpose, repair, refurbish and remanufacture (in the use phase); and recycle and regenerate (in the after-use phase). These pathways work together to extend the lifespan of products and components, reduce resource throughput, and maximise the utilisation of materials.

Prioritising shorter material loops is enabled by the circular design of products, business models, and systems. This paper outlines circular economy strategies and pathways, emphasising the importance of circular design across all levels. The circular economy is not a waste economy nor a recycling economy; it encompasses product design, business model design, and system design at the micro, meso, and macro levels. This holistic approach assesses the environmental impact of each intervention, focusing not only on the quantity but also on the quality of circular loops. The goal is to systematically eliminate waste and reduce resource use from the outset, achieving a truly regenerative economy.

Figure 1-1: The 10Rs in a circular economy



The 10R strategies are spread across the design, use, and after-use phases of a product:

Design phase: Smarter design for products and systems

The design phase emphasises the re-thinking and re-shaping of products and systems. Since design sits upstream of the product value chain, it has a decisive impact on the behaviours of downstream actors and the system itself. It is primarily implemented through pathways of refuse, redesign, and reduce.

Refuse: Preventing the use of materials that are harmful or impossible to recycle in the creation of goods and services, and demanding fewer short-lived goods where possible. *(Banning non-recyclable plastic resin types and reducing consumption of disposable plastic packaging and fast fashion items where alternatives exist)*.

Redesign: Designing products and their production processes to enable other R-strategies. *(Designing a smart-phone for durability, disassembly, and recyclability so it can more easily be maintained, refurbished, reused, and recycled)*.

Reduce: Minimising the use of raw materials and energy in product manufacturing using different methods or substitute renewable materials grown using regenerative practices. *(Producing modular, prefabricated wooden building components, which are less material and energy-intensive and generate less waste than employing traditional construction methods)*.

Use phase: Extending the lifespan of products and components

The use phase primarily focuses on extending a product's lifespan and delaying reaching the end of life by maximising its frequency and diversity of use. Circular pathways during this stage can be categorised into reuse, repurpose, repair, refurbishment and remanufacture. The appropriate pathway should be chosen based on the product's attributes and supply chain characteristics.

Reuse: Repeatedly using a product or component for its intended purpose without significant modification. *(Business models such as renting or sharing bicycles and power banks, or reselling clothes via digital platforms)*.

Repurpose: Adapting and utilising materials, components, and products into different applications for alternative purposes. *(EV batteries that no longer meet the performance standards for their original use can be used for energy storage in homes and other industries)*.

Repair: Returning a faulty or broken product or component to a usable state to fulfil its intended use. *(Replacing the cracked screen on a smartphone rather than discarding or recycling the whole phone)*.

Refurbish: Returning a product to good working order. This can include repairing or replacing components, updating specifications, and improving cosmetic appearance. *(Fitting a battery pack with improved storage capacity to an existing smartphone)*.

Remanufacture: Re-engineering products and components to as-new condition with the same, or improved, level of performance as a newly manufactured one — with a warranty to match. *(An Original Equipment Manufacturer remanufacturing a car engine, replacing and refurbishing components as necessary, to achieve an overall level of quality equivalent to a new engine)*.

After-use phase: Maximising the utilisation of materials

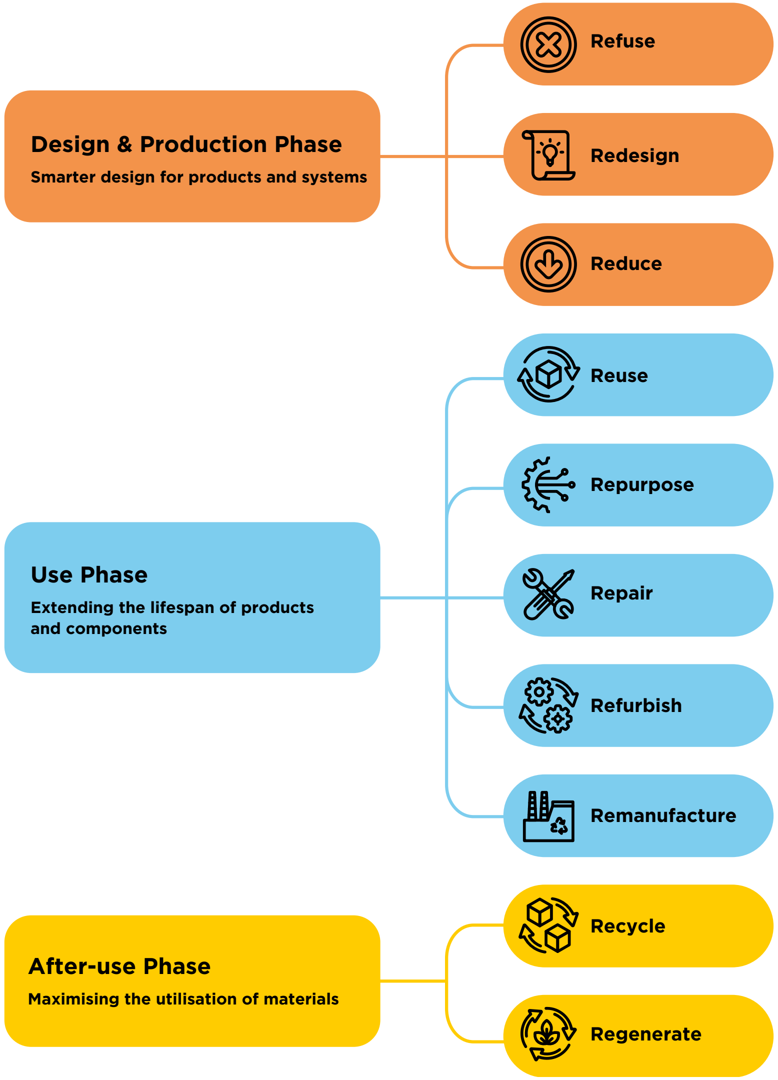
Once the use phases are complete, after-use pathways of Recycle and Regenerate come into play. While these loops entail the loss of greater amounts of embedded energy and value than the inner loops described above, they are crucial to avoiding materials being sent to landfill or being incinerated once they have been used.

Recycle: Transforming a product or component into its basic materials or substances and reprocessing them into new materials — only after higher value pathways have been exhausted.[i] *(Recycling PET from drinks bottles into rPET for use in new drinks bottles [closed loop], or for use in other industries [open loop])*.

Regenerate: Converting organic by-products with no alternative uses into materials that do have a use, with or without the generation of energy as a by-product (biogas). *(Using anaerobic digestion to convert agricultural residues, food offcuts, and sewage sludge into digestate [biosolids], for use as a soil enhancer, and biogas for energy)*.

i Closed-loop recycling transforms materials to make new products of the same type, such as turning used plastic bottles into new ones. Open-loop recycling generates raw materials for other products, potentially in other industries, such as turning used aluminium engine parts into new aluminium foil or cans.

Figure 1-2: The 10R at each stage of the product life cycle



Box 1: The circular economy is regenerative by design

This means that flows of materials and food, and patterns of land use in rural and urban areas, are designed in ways that support positive outcomes for nature, which include healthy soils, improved biodiversity, and higher air and water quality. In agriculture, regenerative production schools of thought include agroecology, agroforestry, and conservation agriculture. In other industries, substituting for bio-based materials — for instance wood for construction or bio-based plastic resins — should take biodiversity and land use change into consideration, for example, by applying regenerative forestry practices. Across the economy, biological by-products — for instance from homes, farms, and textile factories — are collected to be composted and returned to the soil. The industry most clearly shaped by the regenerative principle is food, which is not covered in this paper. However, the principle is relevant, to a greater or lesser extent, to all industries and contexts. Integrating nature and restoring natural processes into the design of the built environment improves air and water quality, provides climate regulation and flood protection, and restores native landscapes. Such actions have positive impacts on local communities since human health and wellbeing directly benefit from nature regeneration.

1.3 The circular economy offers a 'triple play' solution for achieving climate objectives

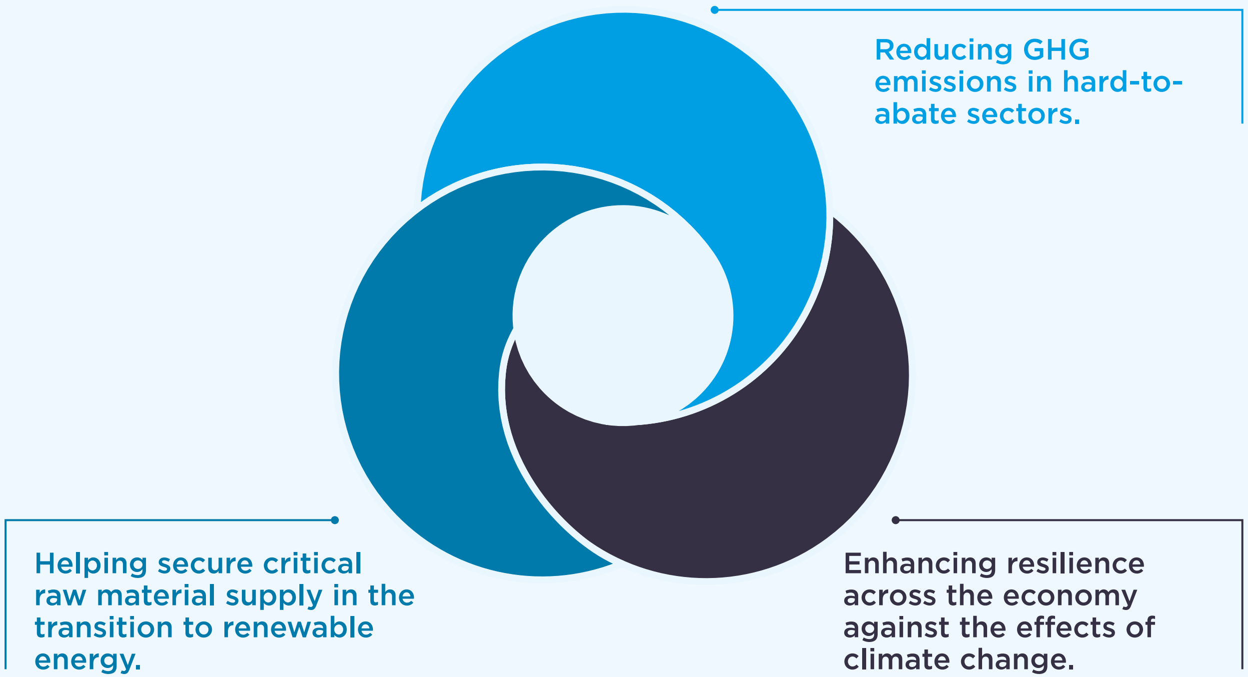
The circular economy offers a powerful, integrated approach to tackling climate change by addressing its root causes and fostering growth that is more resilient to projected climate impacts. The principles of the circular economy — eliminating waste and pollution, keeping products and materials in circulation, and regenerating natural systems — together serve to transform the way we produce and consume goods and services, and offer a 'triple play' solution for achieving climate objectives:

Reducing GHG emissions in hard-to-abate sectors. By circulating carbon-intensive materials such as metals, cement, and plastics in sectors like mobility and the built environment that make heavy use of them, the circular economy reduces GHG emissions in the upstream industries that extract and process these materials.

Helping secure critical raw material supply in the transition to renewable energy. China is rapidly shifting from fossil fuels to a material-intensive renewable energy system. Circular economy solutions that circulate critical raw materials in these supply chains are crucial to ensuring China achieves a lasting and sustainable transition.

Enhancing resilience across the economy against the effects of climate change. By designing diversified, resilient supply chains and applying regenerative practices, the circular economy can help industries adapt to the increasing risks posed by resource shortages and extreme weather events driven by climate change.

Figure 1-3: The circular economy as a triple solution for advancing China's climate action



This 'triple play' solution, acting as an interconnected mechanism, contributes to a comprehensive framework for addressing climate change in China:

1. Circular economy reduces greenhouse gas emissions in hard-to-abate sectors

Similar to enhancing energy efficiency and transitioning to low-carbon energy sources, the circular economy is pivotal for achieving a low-carbon transformation in the supply and demand of goods and services. At its core, the circular economy decouples economic development from the consumption of materials, including those that are carbon-intensive to produce, such as metals, cement, plastics, and food.

Research by the Ellen MacArthur Foundation indicates that the circular economy can reduce global GHG emissions from the cement, steel, plastic, and aluminium industries by 40%, with reductions of 10% from waste minimisation, 12% from extending product lifespans, and 18% from promoting material recycling.[4] These reductions are from upstream 'hard-to-abate' industrial sectors, such as mineral ore processing and cement manufacture, that at present find it technically and economically difficult to switch to renewable sources of energy. Estimates by the China Association of Circular Economy indicated that circular economy measures contributed to a 25% overall reduction in China's carbon emissions during 2016-2020, with projections of 30% by 2025 and 35% by 2030, compared to the Business As Usual (BAU) scenario.[5] Therefore, effectively integrating the circular economy into climate mitigation efforts can support China's transition to a low-carbon economy.

2. Circular economy helps secure critical raw material supply in the transition to renewable energy

While 45% of global GHG emissions are derived from producing products and food, the remaining 55% is linked to energy use.[ii] The transition to renewable energy is critical in achieving the targets set by the Paris Agreement on climate change and China's goal of achieving carbon neutrality by 2060. However, the renewable energy transition is a major shift from a fuel-intensive to a material-intensive energy system. This means increasing the use of minerals by at least four-fold by 2040 and thereby increasing emissions from processing ores and manufacturing equipment (which sit in the 45% portion). To decouple demand for critical raw materials from this growth, and to minimise increases in industrial emissions, the renewable energy sector should transition toward a circular economy.

The manufacture of wind turbines and solar PV equipment in China — for domestic use and export — is expected to continue its robust growth, reinforcing the country's global leadership in these sectors. The 'National Plan for Mineral Resource (2016-2020)' identifies 24 critical minerals[6] in these supply chains, including copper, lithium, and rare earths, with more than half heavily reliant on imports. While China has secured some critical mineral reserves through overseas investments, supply chain stability is subject to risks of geopolitical tension, market volatility, and resource nationalism.

Furthermore, designing the next generation of wind and solar equipment for circularity would avoid the large-scale resource waste, soil degradation, and water pollution associated with landfilling decommissioned equipment.

ii Analysis from the International Resources Panel (IRP) and the United Nations Environment Panel (UNEP), while different in scope and approach, has arrived at similar figures. In their Global Resources Outlook 2019, the two organisations found that GHG emissions from the extraction and processing of resources make up about half of the global total, and in the 2024 edition of the report found that this figure had increased to 55%.

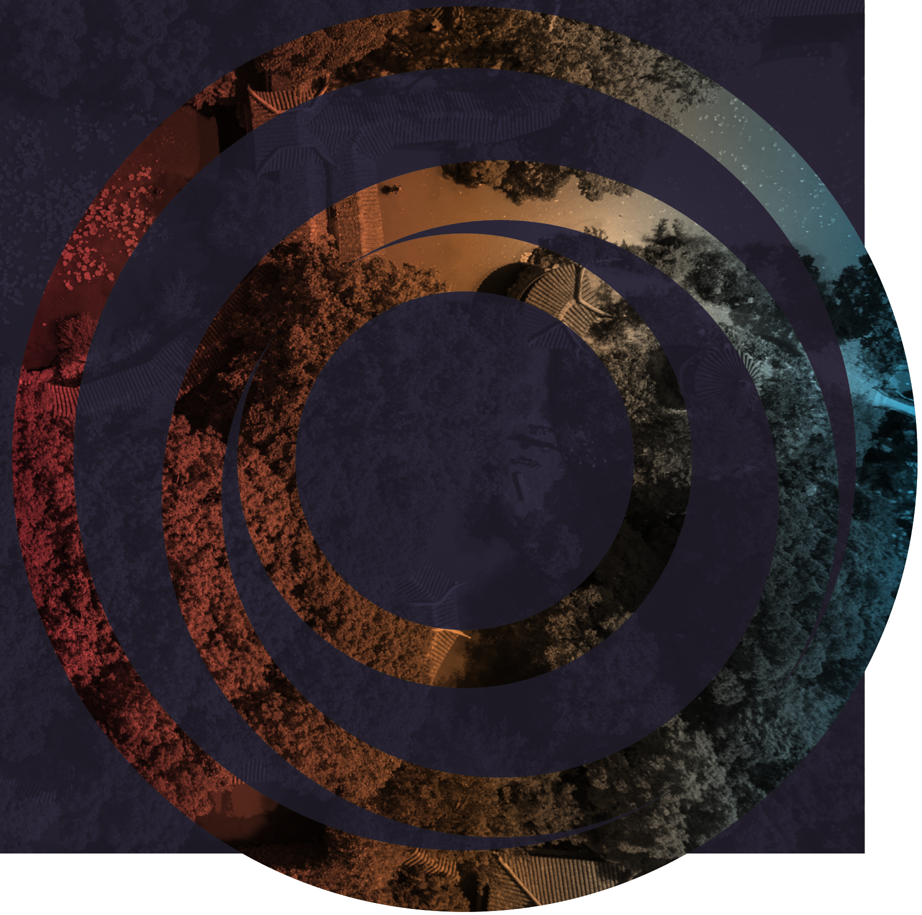
3. The Circular economy enhances resilience across the economy against the effects of climate change

Evidence suggests that the diversified and interconnected supply systems created in the circular economy can enhance climate adaptation capabilities.[7,8] Circular supply chains enable businesses to become more resilient by decoupling operations from the extraction of natural resources, thereby increasing the security of materials supply and reducing exposure to material price volatility. For example, expanding capacity for repair, reuse, and sharing can improve access to essential goods and services in periods of supply disruption, such as those caused by extreme weather events.

Circular economy activities can also increase resilience to the effects of climate change by regenerating nature. Incorporating nature into urban planning by increasing tree canopies and regenerating native vegetation and water habitats increases the resilience of citizens and businesses to the effects of climate change by reducing peak temperatures (by increasing shade and reducing the urban heat island effect) and reducing flood intensity (by slowing water flows and increasing infiltration). Importantly, in the food sector, regenerative agricultural practices improve soil health, leading, for instance, to its greater capacity to absorb and retain water, thereby increasing the resilience of food production to both intense rainfall and drought.

Chapter 2

The circular economy is crucial to reducing emissions in hard-to-abate sectors in China



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China's economic transition is expected to shift emissions from production to consumption.

China's economic transition is shifting the balance from production-related to consumption-related emissions.[iii] China's rapid rise to become one of the world's largest economies and exporters of goods has been primarily driven by its manufacturing sector, which has been a major contributor to China's environmental impacts including climate change. China's carbon neutrality goals are reshaping the future trajectory of its industry which will be characterised by a greater focus on advanced technology and manufacturing. In parallel, China is transitioning from a production-oriented society to a consumption-oriented one, demonstrating significant potential to meet increasing societal needs and wants. It has already become the world's second-largest consumer goods market. As the domestic consumer market continues to expand, China's emissions are expected to start shifting from production-based towards consumption-based.

Circular economy is crucial to bringing down both embodied and operational (use phase) emissions from consumption.[iv] Reducing emissions from consumption can be tackled in two ways. By reducing the emissions currently inherent in manufacturing processes (the supply side) or reducing the number of new products made (the demand side). Both are crucial if emissions are to fall fast enough to meet international climate targets. The circular economy is a powerful tool in tackling emissions from the demand side while still meeting people's needs since it generates much more economic value from each tonne of raw material than a linear take-make-waste economy. This is important because, while some manufacturing processes can be run on currently available renewable energy technologies at an industrial scale, others such as cement production and metal smelting are not yet at that point.

iii The carbon emission accounting system can be divided into production-based and consumption-based emissions. Production-based accounting focuses on emissions within the production location, ignoring carbon transfer through trade, as outlined by the IPCC guidelines. Consumption-based accounting considers emissions from consumption activities, including both operational emissions (from daily energy use) and embodied emissions (from the entire life cycle of goods). Consumption-based carbon accounting provides a clearer depiction of the carbon footprint in economic activities, assesses the carbon emission dynamics of different consumers, and better clarifies the responsibilities of producers and consumers, helping select appropriate emission reduction strategies

iv Emissions from consumption can be categorised into embodied and operational (in-use) emissions. Operational emissions refer to those generated from daily energy use, while embodied emissions encompass the embodied carbon from the manufacturing of consumer goods and the provision of services.

2.1 Three high-carbon sectors are good examples of increases in consumption-related emissions

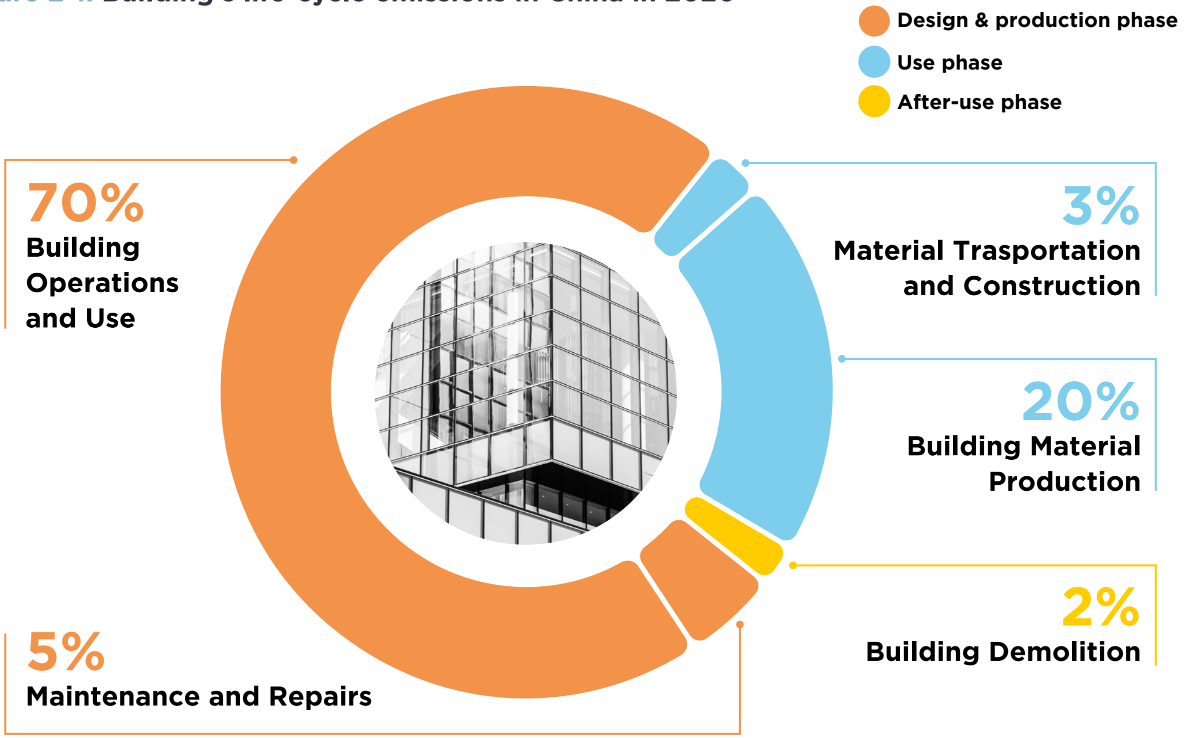
To strategically address the carbon footprint of China's consumption-driven economy, attention needs to focus on sectors essential to meeting the needs of China's rapidly urbanising and increasingly affluent population. This chapter focuses on three illustrative examples of such sectors: residential buildings, mobility, and plastics. While they do not provide a comprehensive view of all consumption-related emissions in China, they are key examples that together emit approximately 4.8 billion tonnes of CO_2 annually (40% of the national total), underscoring their substantial role in China's evolving emissions profile.

Residential buildings

China's rapid building expansion has led to significant carbon emissions. Buildings not only meet the diverse spatial needs for living, working, and entertainment, but also reflect the pursuit of higher quality of life. In recent decades, rapid socio-economic development has led to accelerated urbanisation alongside a substantial increase in rural residential building. This growth has improved living and working conditions and has promoted the modernisation and functional upgrade of urban and rural landscapes. However, the rapid expansion of buildings has also posed challenges in terms of resource consumption leading to significant GHG emissions.[v] In 2020, China's residential building sector emitted approximately 3.7 billion tonnes of CO_2e,[9] representing around 30% of the nation's total emissions. This includes 1.5 billion tonnes from embodied emissions (materials and construction) and 2.2 billion tonnes from operational emissions (energy use).

Reducing embodied emissions is the next frontier in achieving climate targets for residential buildings in China. While operational emissions — from, for example, heating and cooling — currently account for a significant share of total emissions, the landscape is evolving. As buildings become more energy-efficient and energy sources transition to low carbon alternatives, the need to tackle embodied carbon — emissions from the materials and construction processes used to build the building — has become critical. Without addressing embodied carbon, China will fall short of achieving its climate targets in this sector.

Figure 2-1: Building's life-cycle emissions in China in 2020



v Building carbon emissions are calculated using two methods: the Life Cycle Assessment (LCA) and the Emissions Inventory method. LCA calculates the total emissions of a building over its entire lifecycle, from material extraction to demolition. The Emissions Inventory method focuses on society's annual building-related emissions, covering production, transportation, construction, demolition, and operation.

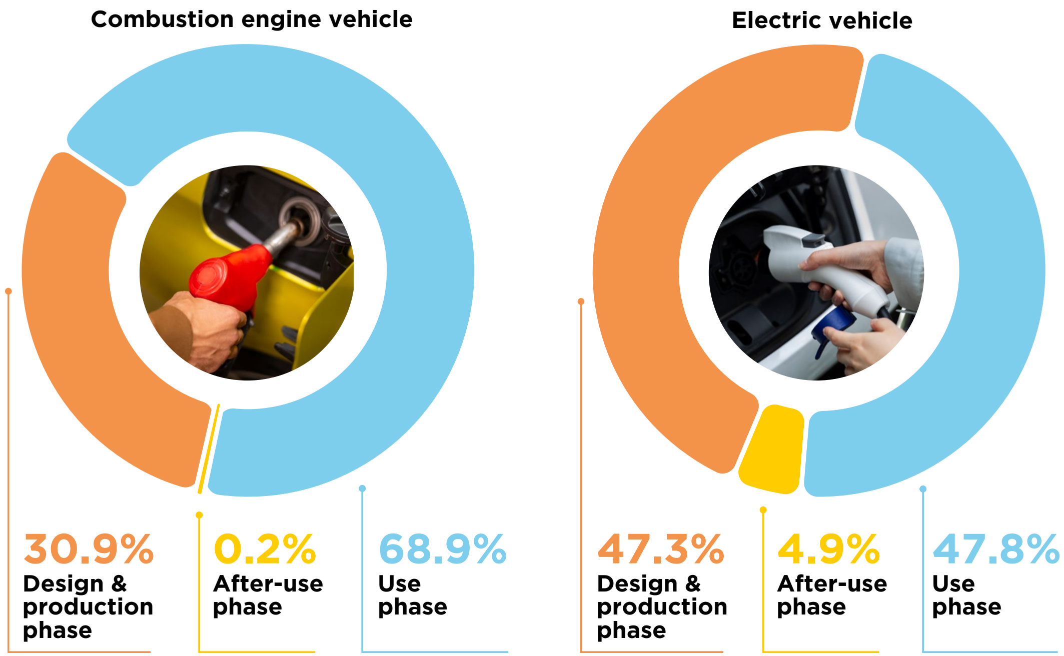
Mobility

Transport is the third largest source of carbon emissions in China, with passenger vehicles the dominant contributors. Decades of strategies reliant on fossil fuels and carbon-intensive industrialisation have entrenched the sector as a major emitter. In 2020, passenger vehicle sector, as the primary mode of meeting mobility demand in China, produced approximately 700 million tonnes of total life-cycle carbon emissions, encompassing both material and fuel cycles.[10] EVs are often touted as a key solution to passenger car decarbonisation. Breaking down cradle-to-grave emissions by power type and based on the national-average electricity mix, internal combustion engine (ICE) vehicles generate 31% of their emissions during production and 69% during use. In contrast, battery electric vehicles (BEVs) show a more balanced split, with 47% of emissions from production and 48% from use (see Figure 2-3). The overall cradle-to-grave emissions for BEVs remained comparable to ICEs in 2019, primarily due to the reliance of the former on coal-fueled electricity, especially in northern China, and their higher demand for metals during the production phase.[11]

China's passenger vehicle ownership has substantial growth potential, with total cradle-to-grave vehicle emissions expected to rise. Rising demand for personalised, timely, and comfortable mobility will drive higher material consumption, energy use, and carbon emissions.[12] Currently, China has 226 vehicles per 1,000 people — only half the level of Japan and a quarter of that in the US.[13] According to the International Transport Forum, China will account for one-sixth of the global increase in passenger mobility by 2050.[14] This trajectory poses significant challenges to China's climate ambitions, underscoring the urgent need for comprehensive emission reduction strategies.

While efforts to reduce use-phase emissions are well underway, the need to cut embodied emissions is becoming urgent. China is transitioning to EVs at an unprecedented pace to cut carbon emissions from vehicle use. In 2023, China's passenger car sales exceeded 26 million units, with EVs reaching a penetration rate of 35%.[15] As EVs are increasingly powered by renewable energy and battery performance improves, their use-phase CO_2 emissions have significantly decreased and are expected to continue to decline. Research shows that from 2015 to 2020, the use-phase CO_2 emissions of BEVs in China dropped from being 34% lower than ICEs to being 57% lower, and are projected to be 69% lower by 2030.[16] However, challenges remain in reducing carbon emissions during the manufacture and end-of-life phases of the materials cycle, where progress has been slower. This highlights the urgent need for stronger technology-enabled interventions on the demand side, such as improved access to mobility-as-a-service.

Figure 2-2: Life-cycle emissions of two types of passenger vehicles in 2019

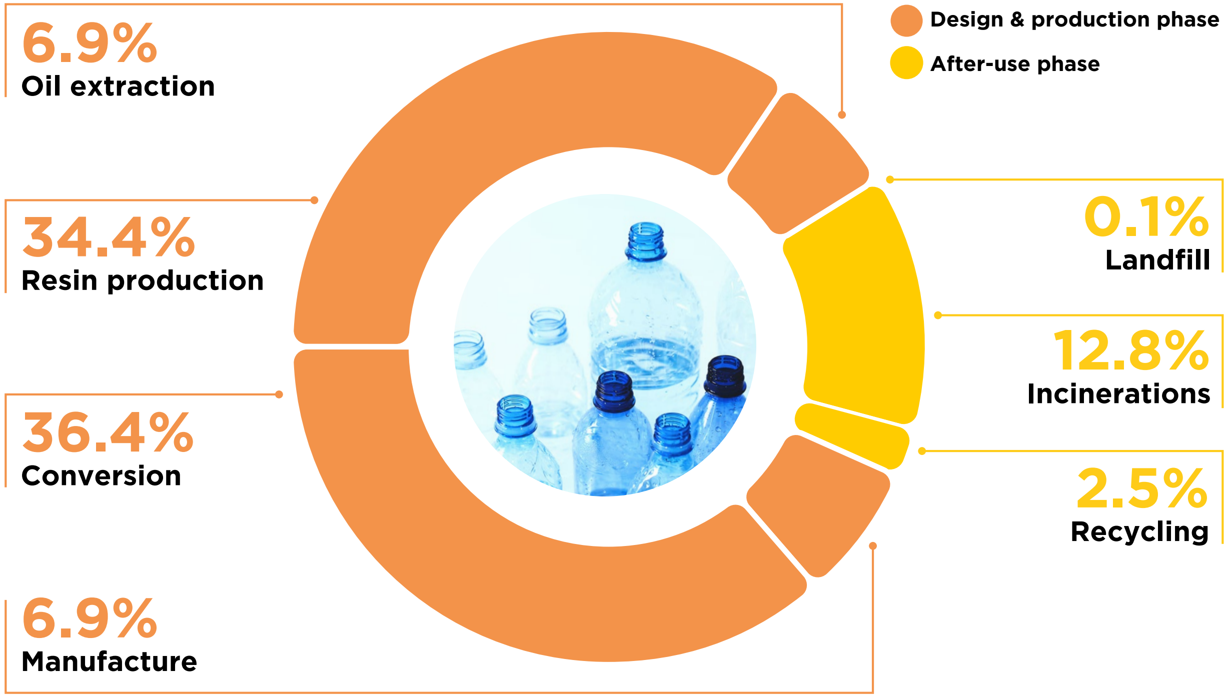


Plastics

China's plastics sector operates on a linear take-make-waste model. Plastics have a wide range of applications and are omnipresent in people's daily lives. In 2022, China's plastic production reached 78 million tonnes, ranking as the biggest producer globally.[17] Plastic packaging is the dominant application, accounting for nearly half of all plastics used in China by weight.[18] The large rates of production, use, and disposal of plastic packaging and products, particularly single-use items, have led to substantial waste and pollution challenges. These have continued to grow significantly over the last years, amongst other reasons because of robust growth in e-commerce and online food delivery. It is estimated that of the 63 million tonnes of discarded plastics generated in China in 2022, an estimated 30%[19] were recycled—significantly surpassing the global average of 9%[20] —while the majority was disposed of through landfilling or incineration.

While plastic pollution is frequently discussed, its climate impact is often overlooked. Research has indicated that each stage of the plastic lifecycle, except the use phase, has significant emissions, with the manufacturing stage being the most dominant. The Chinese plastic sector emitted approximately 436 million tonnes of CO_2e in 2020 (see Figure 2-4), excluding carbon offsets from recycling.[21] This accounts for 3.4% of China's total GHG emissions. Upstream production and manufacturing accounted for 85% of these emissions, with the remainder coming from downstream end-of-life activities. Based on the BAU scenario, life-cycle emissions from China's plastics sector are expected to increase sharply, with an average annual growth rate of 1.5%,[vi] reaching 720 million metric tonnes of CO_2e by 2060 — more than twice the 2020 level.

Figure 2-3: China's plastics sector life-cycle emission in 2020



vi According to Tsinghua University, the average annual growth rate of plastics between now and 2030 is likely to be around 2% to 3%. After 2030, the rate is expected to decrease to below 1.5% due to stricter plastic pollution controls and material substitution efforts.

2.2 The circular economy offers emissions reduction potential in all three high-carbon sectors

Residential buildings

Refuse **Repair** **Refurbish**

Making the most of existing building stock rather than relying only on its expansion should be the priority for reducing carbon emissions in the building sector in China. China's building model has been shifting from meeting basic needs through increasing supply to enhancing building performance and functionality through demolition and new construction. In this model, the average building lifespan is reduced to about 30 years, far below its structural life expectancy, leading to high demand for steel and cement and consequently elevated carbon emissions. Compared to demolition and new construction, repairing, refurbishing, and retrofitting existing structures can offer more cost-effective, less resource-intensive, and lower emission solutions to improving the building stock. Circular renovation projects should ensure that upgrades increase building durability (e.g. by selecting longer-lasting materials), adaptability (e.g. by applying modular design), and energy-efficiency (e.g. by better insulating them), and should use low impact, reused, and recycled materials.

Redesign

Compact city design and regenerating nature in urban areas are crucial elements of urban planning in the circular economy. Compact city design, including the reuse of brownfield sites and vacant buildings where possible, prevents urban sprawl and makes the most of often underused resources. Regenerating nature in the city can also contribute to carbon sequestration and climate adaptation. Increasing tree canopies and areas of water and vegetation, through 'sponge city' initiatives for example, can sequester carbon, improve air quality, increase resilience to extreme weather events, and reduce peak temperatures.

Passive building design helps reduce energy demand, thus cutting use-phase emissions. Passive design techniques primarily focus on enhancing the thermal insulation and airtightness of building envelopes while incorporating passive heating, cooling, and natural ventilation and lighting technologies to reduce energy demand. In 2020, the Ministry of Housing and Urban-Rural Development issued the 'Green Building Action Plan', promoting the comprehensive implementation of circular design in new buildings. The Shenzhen Institute of Building Research Headquarters is a prime example of integrated design, with office area electricity consumption at 60.2 kWh/m^2 per year — 40% lower than similar buildings in Shenzhen. It is estimated that by 2050, the widespread adoption of integrated and passive design could reduce China's emissions by 964 million tonnes annually.

Redesign

Modular design and prefabricated buildings are rapidly developing in China and becoming a significant force for emission reduction. Prefabricated buildings, which use factory-made components assembled on-site, can significantly reduce waste and carbon emissions while improving construction efficiency and safety. Compared to traditional building methods, prefabricated buildings offer substantial benefits: it is estimated that they can cut water use by 20%, carbon emissions by 8%, and waste generation by 78% per square metre.[22] With strong policy support, the adoption of prefabricated buildings is increasing. The 'Carbon Peak Implementation Plan in Urban and Rural Construction' aims for prefabricated buildings to constitute 40% of new urban buildings by 2030. Despite challenges in cost control and skill development, integrating the value chain and establishing harmonised standards can further promote this circular intervention.

Reduce

Low-carbon building materials present opportunities to reduce emissions embodied in new buildings. China's overarching 'Action Plan for Carbon Peak by 2030' emphasises two material substitution options to decarbonise construction projects. One is to use low-carbon steel and cement. Steel production processes can be reshaped by using alternative substances to reduce ore. Globally, approximately 5% of steel is produced using the Direct Reduced Iron (DRI) process, which does not require coke.[23] For cement production, part of the clinker can be replaced with low-carbon materials. Beijing Daxing International Airport, China's largest, utilised low-carbon concrete technology during its construction, reducing carbon emissions while enhancing structural strength and durability. It is estimated that low-carbon production of building materials could reduce emissions by 130 million tonnes annually by 2050 in China. Another option is to use renewable materials, such as wood and bamboo, which are easy to harvest, transport, and are widely available in China. When using renewable materials, it is critical to ensure they are sourced from well-managed woodlands or sourced under a recognised certification scheme, and to avoid the permanent destruction of natural carbon sinks and biodiversity. Furthermore, the use period of renewable materials should align with the replenishment rate of the resource.

Recycle

Recycling construction waste holds significant emission reduction potential. The composition of construction and demolition waste (CDW) varies depending on the type of building demolished and includes soil, dust, bricks, concrete, asphalt, glass, wood, plastic, metal, organic impurities, and other debris. The 2020 'Carbon Peak Implementation Plan for Urban and Rural Construction' outlines a strategy to advance the centralised processing and cascaded utilisation of CDW, aiming to achieve a 55% resource utilisation rate by 2030. It is estimated that China generates over 2 billion tonnes of urban construction waste annually, accounting for 30-40% of urban solid waste generate.[24] Studies indicate that reusing one tonne of construction waste can reduce carbon emissions by 100 kg,[25] leading to an annual carbon reduction potential of 120 million tonnes.

Mobility

Redesign

Providing digitally-enabled, on-demand, zero-emission, multi-modal transport is an important aspect of the circular economy in cities. An urban mobility system, tailored to the needs of fast-growing city populations, integrates zero emissions public transport with various types of shared and private vehicles. Such a system would be supported by a digital platform that enables trip planning, a single-payment solution, and thus a convenient experience for the user. The explosive growth observed in certain forms of shared transport demonstrates the appeal and potential of a new type of mobility system, but a coordinated and coherent strategy will be needed to ensure it is tailored to the needs of passengers. Elements of city-wide mobility system design include: compact city development for effective mobility; freight strategies for reverse logistics and resource loops; infrastructure for zero-emission vehicles; and big data solutions to optimise mobility systems.

Redesign

Lightweight vehicle design can reduce embodied emissions. Reducing vehicle weight is essential for improving fuel efficiency and range, leading to a demand for lightweight designs. One approach is optimising structural design to eliminate redundant parts. For example, Tesla's Shanghai Gigafactory's integrated casting technology for the Model Y reduced the number of casting parts from 70 to 2, decreasing overall weight by 30%. Another approach is using lightweight materials to reduce component weight. Research indicates that from 2019-2050, material lightweighting (e.g. replacing steel with aluminium, magnesium, or carbon fibre) will contribute to a cumulative carbon reduction of 4.1 billion tonnes in China's passenger vehicle sector,[26] averaging 128 million tonnes annually. Despite starting later than the EU and the US, China has made significant progress in vehicle lightweighting, especially in EVs.

Reuse

Ride sharing is a business model that can enable emission reduction. The rapid development of digital technology has given rise to the sharing economy. Ride-sharing, a typical customer-to-customer (C2C) shared mobility method, combines increasing seat utilisation, reducing the number of vehicles on the road, and alleviating traffic congestion. In the short term, demand-side mitigation strategies — such as driving less, sharing vehicles, and reducing personal car ownership — are proving more effective than technological advances in EVs. These demand-side strategies can deliver CO_2 emission reductions of 22% compared to 16% from technology-oriented strategies.[27] Statistics show that ride-sharing on platforms like Hailo, Didi, and T3 has collectively reduced carbon emissions by 3 million tonnes annually.[28,29,30] Looking to the future, shared autonomous vehicles (SAVs) represent the next evolution of circular mobility. Research suggests that the large-scale adoption of electric, shared autonomous driving could result in a cumulative carbon emission reduction of 3.8 billion tonnes in China's transportation sector between 2020 and 2060,[31] with an average reduction of 93 million tonnes annually.

Reuse

Revitalising the used car market is essential for extending vehicle lifespans and reducing carbon emissions. A study of Japan's passenger car market (1993-2014) revealed that a 10% increase in used car market share could reduce carbon emissions by 16.9 million tonnes.[32] In China, used car transactions reached nearly 18 million in 2021, or 67% of new car sales volume.[33] To unlock the full potential of this market, China has lifted restrictions on inter-regional vehicle transfer and simplified registration processes for used cars. The 'Action Plan for Large-Scale Equipment Renewal and Consumer Goods Trade-In' targets a 45% increase in the used car market by 2027 compared to 2020. Combining this market revitalisation with policies banning the sale of new fuel vehicles and promoting EVs can maximise emission reduction, as together they accelerate the replacement of high-emission vehicles with lower-carbon alternatives.

Repurpose

Using retired batteries for other energy storage purposes reduces emissions and keeps valuable materials in the economy. Qualified retired power batteries, after testing, maintenance, and reassembly, can still be used in other energy storage applications. As of the end of 2022, China Tower had used 510,000 sets of second-life batteries across approximately 250,000 communication base stations in 31 provinces, expanding their application to low-temperature, high-altitude, and other specific scenarios. The maximum carbon reduction potential of reusing 1 kWh of lithium iron phosphate and ternary lithium 811 power batteries is 194 kg.[34] Projections indicate that between 2020 and 2050, a cumulative 16 TWh of power batteries will be retired from EVs in China.[35] If fully reused, the annual average carbon reduction could be around 100 million tonnes.

Remanufacture

Increasing automotive parts remanufacturing is key to reducing embodied emissions. By 2018, China had 240 million vehicles, with most having a lifespan of over ten years. With a standard 5% scrappage rate, China is expected to see a peak in vehicle scrappage post-2020, expanding the end-of-life vehicle market to a trillion-yuan scale. Prioritising remanufacturing for end-of-life vehicles, especially key components like engines, steering systems, transmissions, axles, and frames, is crucial. For example in Europe, annually, remanufacturing of passenger car components avoids approximately 490 kt CO_2e, while remanufacturing of commercial vehicle components avoids approximately 317 kt CO_2e. This is equivalent to the annual emissions produced by 120,000 European citizens.[36] China's remanufacturing rate remains below 10%, considerably lower than that of developed economies, where rates can reach up to 45%.[37] However, China has made progress through pilot projects and industry promotion. The 2021 'Interim Measures for the Management of Automotive Parts Remanufacturing' introduced strict quality standards, information traceability, product labelling, and efficient management of old parts, paving the way for standardised, large-scale development.

Recycle

Enhancing the recycling of after-use vehicles and integrating recycled materials into new vehicle manufacturing is crucial for improving resource efficiency and reducing carbon emissions. In 2021, over 2.5 million vehicles were scrapped in China,[38] with around 60% of the recyclable materials in them being steel. Metals that cannot be remanufactured are sold to steel companies as raw materials, ensuring that even non-reusable parts contribute to the circular economy. China's 'Extended Producer Responsibility Pilot Programme for Automotive Products' aimed to achieve a 75% recycling rate from scrapped vehicles by 2023. For instance, BMW's partnership with Huayou Cobalt has created a closed-loop recycling system for battery materials, reducing carbon emissions by up to 70% compared to traditional mining.[39] Research indicates that recycling a single end-of-life EV can cut carbon emissions by approximately 5 tonnes, with contributions from steel, aluminium, and battery cathode materials.[40] Between 2022 and 2050, the decommissioning of an estimated 195-269 million EVs in China could result in an annual average carbon reduction of 40 million tonnes if they are fully recycled.[41]

Plastics

Refuse Reduce

Prohibiting the production and use of avoidable and problematic single-use plastics avoids plastic waste and emissions. This is the first critical step towards advancing a circular economy for plastics. For instance, The EU Single-Use Plastics Directive bans ten common plastic items that most commonly end up in the environment, including single-use straws, balloon sticks, plastic cutlery, and plates.[42] In China, a series of policies, starting with the 2008 Plastic Ban and continuing with the 2020 New Plastic Ban, have been implemented to curb single-use plastics. Data shows that since 2008, the annual growth rate of plastic bag usage in China has dropped from over 20% to less than 3% by 2021. Between 2008 and 2016, the use of plastic shopping bags in supermarkets and malls decreased by more than two-thirds, resulting in a cumulative reduction of around 1.4 million tonnes of plastic bags. This reduction is equivalent to nearly 30 million tonnes of CO_2 emissions being avoided annually, with an average annual emission reduction of approximately 3.8 million tonnes.

Redesign

Replacing fossil-based plastics with bio-based alternatives in virgin plastic production can reduce carbon emissions. After minimising the use of plastics and using as much recycled plastics as possible, there will always be some remaining need for virgin plastics. Substituting fossil-based feedstock with bio-based alternatives is part of a circular economy for plastics. Bio-based plastics are derived from renewable resources, boasting a lower carbon footprint due to the carbon dioxide absorption during their growth. For example, some bio-based plastics have been shown to have a negative emissions potential, with -2.2 kg CO_2e per kg of bio-based polyethylene (PE) produced compared to 1.8 kg CO_2e per kg of fossil-based PE produced.[43] China is actively promoting bio-based plastics, as highlighted by the January 2023 issuance of the 'Three-Year Action Plan for Accelerating the Innovation and Development of Non-Food Bio-based Materials'. This plan emphasises enhancing the research, development, and application of bio-based plastics. Switching to bio-based plastics is not a silver bullet and doesn't take away the need to first and foremost reduce the use of virgin plastics. Furthermore, it is crucial to ensure that crops for bio-based plastics are grown using regenerative practices and that land used to grow those crops does not compete with food production.

Redesign

Designing plastics for reusability and recyclability drives down carbon emissions and waste in the plastic value chain. When plastic use is unavoidable, focusing on reusability and recyclability can improve product utilisation and increase recycling rates, thus decreasing the demand for new plastic production and lowering GHG emissions from energy-intensive manufacturing. Achieving this requires innovation and redesign across business models, materials, packaging, and reprocessing technologies. The Golden Design Rules, developed by the Consumer Goods Forum and inspired by the *New Plastics Economy Global Commitment*,[44] offer a framework for designing plastics with recyclability in mind. These guidelines have been adopted by pioneering consumer goods companies in China, helping to reduce waste and emissions and driving industry-wide efforts toward a circular economy for plastics.

Reuse

Reuse models for plastic products and packaging offer tangible ways to reduce waste and emissions in practice. In the case of plastic packaging, there are various business-to-consumer (B2C) models that facilitate reuse, such as refill models where users retain ownership of the packaging and refill it with product either at home or at designated refill stations. If all bottles in beauty and personal care as well as home cleaning were to be reusable and refilled using concentrated refills, packaging and transport savings would represent an 80–85% reduction in GHG emissions compared to today's single-use bottles.[45] A recent study suggests that by 2040, China's packaging industry could lower new plastic production from an estimated 79 million tonnes under a BAU scenario to 9 million tonnes. This shift could reduce life-cycle carbon emissions by 219 million tonnes, with reuse models alone contributing 40% of this reduction — an annual potential to cut emissions by approximately 87.6 million tonnes.[46]

Recycle

Putting in place effective recycling systems and using recycled content in practice are crucial emission reduction levers. Mechanical recycling involves sorting, cleaning, and physically breaking down used plastics to produce new products, thereby circulating materials and keeping them in the economy. Mechanical recycling sits at the heart of today's plastic recycling industry. It is a mature technology, whose economics and methods are well understood. In 2020, China's plastics sector achieved a net emission reduction of 80 million tonnes by replacing virgin plastic production with mechanically recycled plastics. Mechanical recycling delivered a total emission reduction of 110 million tonnes of CO_2, even after taking into account the 30 million tonnes of CO_2 generated by the recycling process itself.[47] With the current recycling rate at just 30%, there is significant potential for further growth. Furthermore, recycling helps industry to shift from high-temperature, energy-intensive manufacturing reliant on fossil fuels to reprocessing focused on collection, sorting, cleaning, and low-temperature heat. Such processes align well with electrification systems, which are easier to decarbonise through the use of renewable energy.

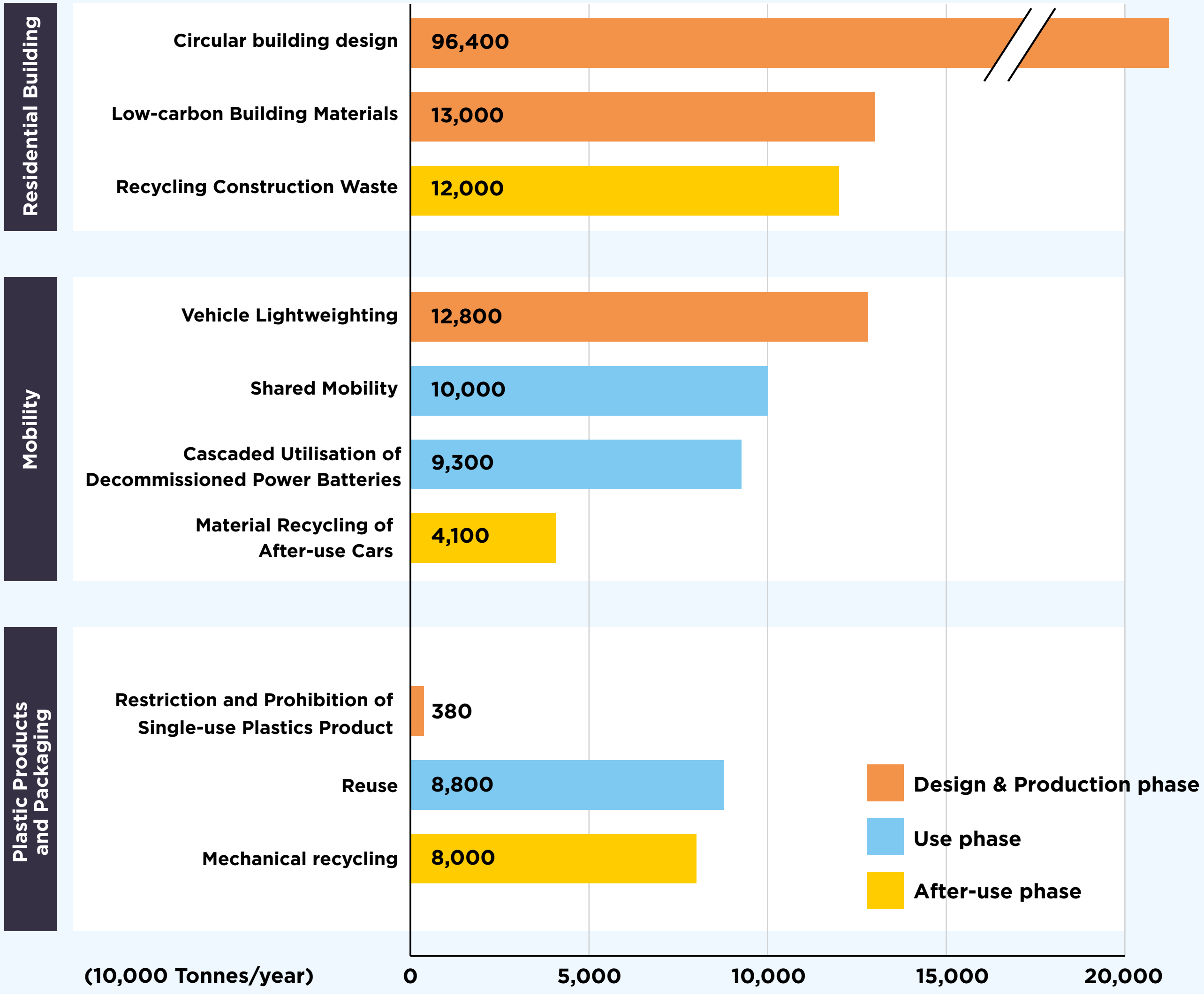
Table 2-1: Circular strategies in the three high-carbon sectors

Sector	Circular strategies	Examples of circular nterventions (a non-exhaustive list)	R-Pathways
Buildings	Smarter building design and construction	Urban planning for nature-positive, liveable, circular cities	Refuse
		Modular, offsite design, and prefabricated buildings	Redesign
		Passive design	Redesign
		Low-carbon construction materials	Reduce
	Extending building lifespan and enhancing space utilisation	Improving the utilisation of building spaces	Reuse
		Extending the lifespan of buildings in the existing stock	Repair, Refurbish
	Maximising use of discarded materials	Recycling discarded building waste	Recycle
Mobility	Smarter vehicle design and manufacture	Mobility systems redesign	Redesign
		Vehicle lightweighting	Redesign, Reduce
	Extending lifespan of vehicles and components	Shared mobility	Reuse
		Second-hand car transactions	Reuse
		Cascaded use of decommissioned EV power batteries	Repurpose
		Remanufacturing of components	Remanufacture
	Maximised use of discarded materials	Material recycling	Recycle
Plastics	Eliminating unnecessary plastics, smarter design and manufacture for plastics that we do need	Banning avoidable and problematic single-use plastics	Refuse
		Designing reusable and easily recyclable plastics	Redesign
		Recycled plastics replacing virgin plastics	Reduce
		Bio-based plastics replacing fossil-based plastics	Reduce
	Extension of the lifespan of plastics	Reuse plastics products and packaging	Reuse
	Keeping materials in the economy at end of life	Mechanical recycling	Recycle

Some quantitative assessments of the emissions reduction effects of key circular interventions are listed in Figure 2-4.

Initial quantitative estimates drawn from a review of the literature reveal that, while exact figures may vary, the potential of a circular economy to reduce emissions is increasingly evident. In hard-to-abate sectors such as residential buildings, mobility, and plastics, the circular economy offers substantial opportunities for carbon reduction. These three sectors currently emit an estimated 4.8 billion tonnes of CO_2e annually, and early estimates indicate that implementing a set of targeted circular interventions could reduce those emissions by approximately 1.8 billion tonnes of CO_2e a year, over a third of the total. Notably, circular interventions implemented at the design and production stage deliver greater emission reduction potential than after-use interventions like recycling, underscoring the importance of upstream innovations for achieving meaningful climate impact.

Figure 2-4: Emission reduction effects of selected circular interventions in the three key sectors



2.3 Three main structural barriers hinder circular economy integration across sectors thereby slowing down climate action

The way GHG emissions are reported can inadvertently disincentivise circular business models. It either leads to inaccurate attribution of emissions or incomplete emissions inventories. A project at the Ellen MacArthur Foundation has identified how emissions accounting frameworks can more fairly and accurately attribute emissions to circular activity. We worked with companies in our Network to capture the reporting challenges faced by businesses leading the circular economy transition. The GHG Protocol standards and guidance, the world's most widely used framework for measuring and managing GHG emissions mainly reflects the dominant linear economic system, assuming one life cycle per product, with one clear beginning and one clear end. However, many businesses are now engaging in circular economy activities that offer multiple beginnings and end-of-life solutions, from cradle to cradle, which are overlooked by the current guidance, leading to inaccurate emissions accounting. This misalignment affects government policy-making and assessment processes, and impedes the development of market mechanisms. For instance, as the emission reduction benefits of circular economy practices cannot be appropriately integrated into corporate climate standards, they will also not be reflected in national carbon trading systems, potentially affecting the international competitiveness of Chinese products under global carbon border adjustment mechanisms.

Circular economy business models face many challenges to their scale-up. Circular economy industries, such as refurbishers, remanufacturers, and recyclers, are crucial in mainstreaming circular practices. However, many of these industries are often outdated, polluting or resource-intensive. For instance, in the recycling industry, Small- and Medium-sized Enterprises (SMEs) make up 70% of the sector, and some technologies used in the recycling process are outdated and energy-intensive, even contributing to pollution. The lack of comprehensive assessments of the economic, resource, environmental, and carbon emission benefits throughout the life cycle of recycling technologies leaves companies without clear guidance in technology selection. Consequently, outdated technologies persist, impeding high-quality development.

The economy is deeply rooted in a linear model, resulting in low demand for circular products and services. Circular and low-carbon products often come with higher price tags, deterring many consumers despite growing interest. Current policy framework and business models are deeply rooted in a linear economic model, failing to internalise the externalities associated with these products. The benefits of circular products are therefore not fully realised, resulting in a market that does not respond as positively as it could. For instance, citizens often opt for cheaper, short-lived materials. This situation creates an uneven playing field in the market, where traditional products outcompete circular alternatives. It is essential to recognise that transitioning to circular products and services presents a significant opportunity for demand-side reform. While this shift will reduce the consumption of traditional high environmental and carbon footprint products, it will also stimulate new consumption demand and economic opportunities, helping redefine the concept of welfare in a more multidimensional way and propel the economy towards high-quality development.

Chapter 3

The circular economy can help China secure raw material supply in its transition to renewable energy

Chapter 3

The circular economy can help China secure raw material supply in its transition to renewable energy

China's wind and solar PV power have grown rapidly, with ambitious expansion set to continue through 2050.

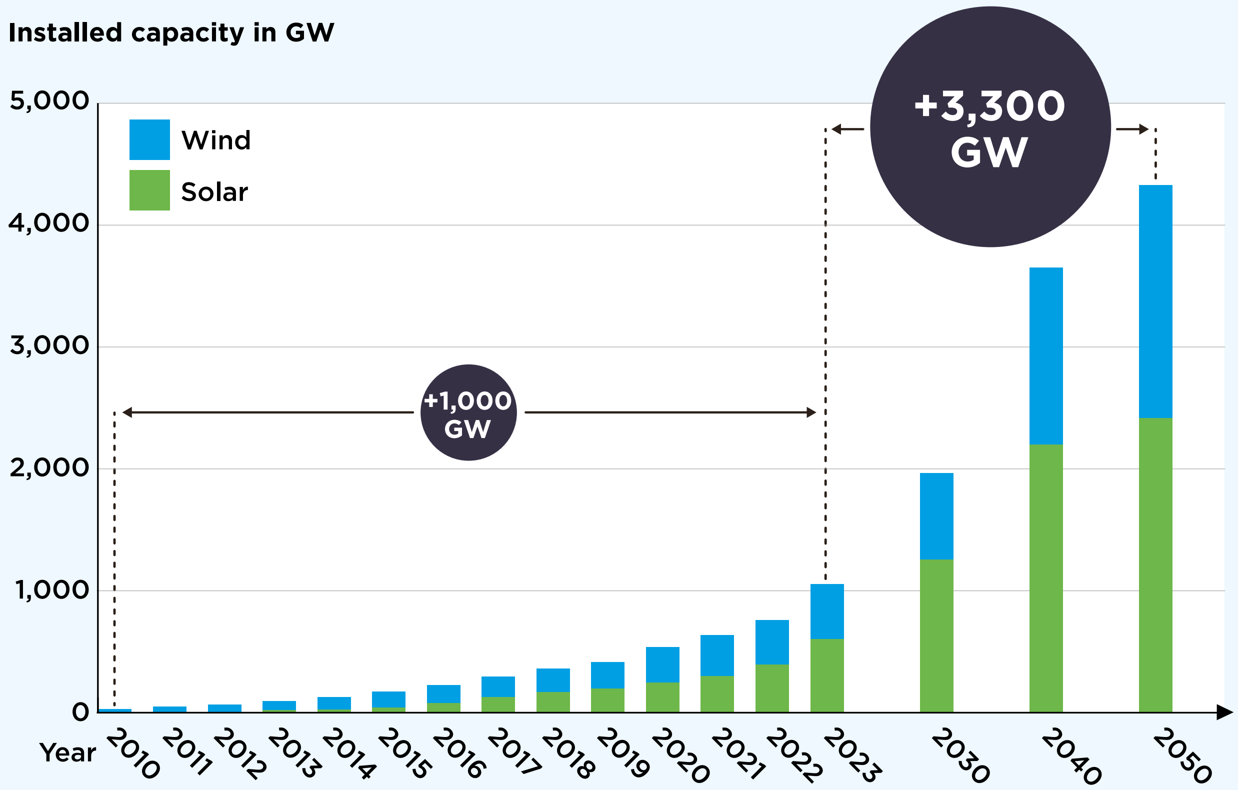
3.1 High demand for critical raw materials and a looming waste problem make a comprehensive circular economy approach essential for China's wind and PV sectors

Driven by China's 'dual carbon' goals - to peak carbon dioxide emissions before 2030 and achieve carbon neutrality by 2060 - the country is asserting its position as global leader in wind and solar power, with twice as much capacity under construction as in the rest of the world combined. In 2023, the sector accounted for 40% of the country's GDP growth.[48] As installed capacity expands, demand for minerals is set to rise sharply, and the dismantling of existing infrastructure will generate large quantities of waste. It is therefore imperative to integrate circular economy practices throughout the value chain to help reduce the demand for primary materials, and strengthen the security of critical raw materials supply to achieve a low carbon and zero waste renewable energy transition.

China's wind turbine and PV installed capacity has increased by 1,000 GW between 2010 and 2023. Since its Renewable Energy Law came into effect in 2006, China has embarked on large-scale deployment of wind and solar energy. China's installed capacity of wind power expanded from around 30 GW in 2010 to 442 GW by 2020.[49] This surge was fueled by strong government incentives, feed-in tariffs, and technological advancements by local companies like Envision. In 2023 alone, China added 75 GW of new wind capacity, accounting for two-thirds of the global increase. The most significant driver of this growth has been China's declining wind energy costs, which dropped by 39% between 2010 and 2020.[50] China's PV capacity also experienced extraordinary growth, increasing from less than 1 GW in 2010 to 610 GW by 2023.[51] Policies such as the 'Photovoltaic Champion Program' and other feed-in tariffs spurred the rapid development of large solar farms and distributed solar systems across provinces including Shandong and Gansu. The sharp decline in solar PV costs — by as much as 82% from 2010 to 2020[52] — also helped accelerate deployment, making solar a key component of China's energy transition. In 2023 alone, China installed more solar panels than the total installed by the USA in its entire history.

China's wind turbine and PV installed capacity is projected to increase a further 3,300 GW between 2023 and 2050. Between 2023 and 2050, China's wind power capacity is anticipated to continue to grow strongly. The cost declines, alongside substantial government initiatives outlined in its Five-Year Plans, have catalysed investments in offshore wind, particularly in coastal regions like Jiangsu and Fujian. Central to China's strategy is the creation of mega 'clean energy bases', which are designed to scale up wind and solar power production in resource-rich regions. China's wind power capacity is projected to exceed 700 GW by 2030 and reach 1,400 GW by 2040 and 1,900 GW by 2050, further cementing its position as a global wind energy leader. China's PV is also set for further rapid growth. PV capacity is projected to surpass 1,200 GW by 2030, driven largely by distributed solar installations in residential and commercial sectors. Technological improvements, alongside policy incentives such as subsidies and tax benefits, are forecasted to push PV capacity beyond 2,200 GW by 2040. By 2050, China's PV capacity could reach 2,400 GW, a critical step towards achieving the 2060 goal of generating over 80% of the country's electricity from non-fossil sources

Figure 3-1: Installed capacity of wind and solar PV energy in China: past and projected[53,54]

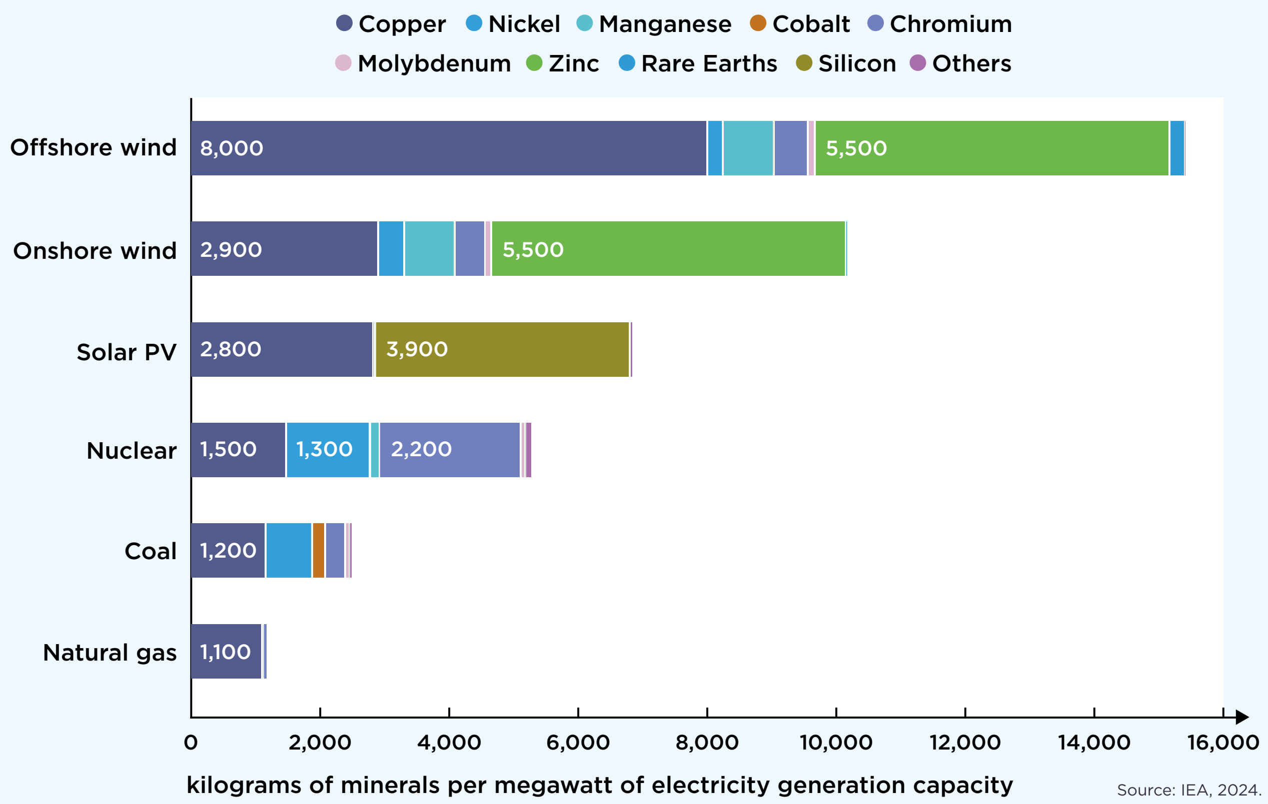


The rapid development of material-intensive renewable energy systems exposes China to raw material supply risks.

Compared to fossil fuel-based power generation technologies, wind turbines and PVs are material-intensive. As shown in Figure 3-2, wind turbines primarily require copper and zinc, while PVs mainly require copper and silicon. The International Energy Agency predicts that demand for critical minerals could more than double by 2040 compared to 2020 levels, with China playing a significant role in driving this increase.[55] While wind turbines and PVs have significantly lower life-cycle CO_2 emissions than their fossil fuel counterparts, their supply chains are responsible for over 90% of life-cycle emissions. Addressing these emissions is therefore crucial for achieving the transition to net zero in these sectors.

China relies heavily on imported materials that are subject to supply risks. China refines and processes most of the materials needed for its wind and PV supply chains. However, for key raw materials such as zinc, copper, silicon, and carbon fibre, it relies heavily on imports, with reliance on six materials (nickel, platinum group metals, tantalum, chromium, cobalt, and zirconium) exceeding 90%. Import sources are highly concentrated: for example, 75% of cobalt comes from the Congo, 68% of copper from Chile, and 60% of nickel from the Philippines.[56] The issue at hand is not the scarcity of critical materials but the reliability of their supply.[57] Despite China doubling down on overseas investments to secure critical mineral supply, this strategy faces challenges including long lead times for mine development (averaging 16 years), geopolitical tensions, high market volatility, and increasing resource nationalism. These factors pose risks to the stability of these supply chains.[58]

Figure 3-2: Critical minerals in fossil vs. renewable energy systems



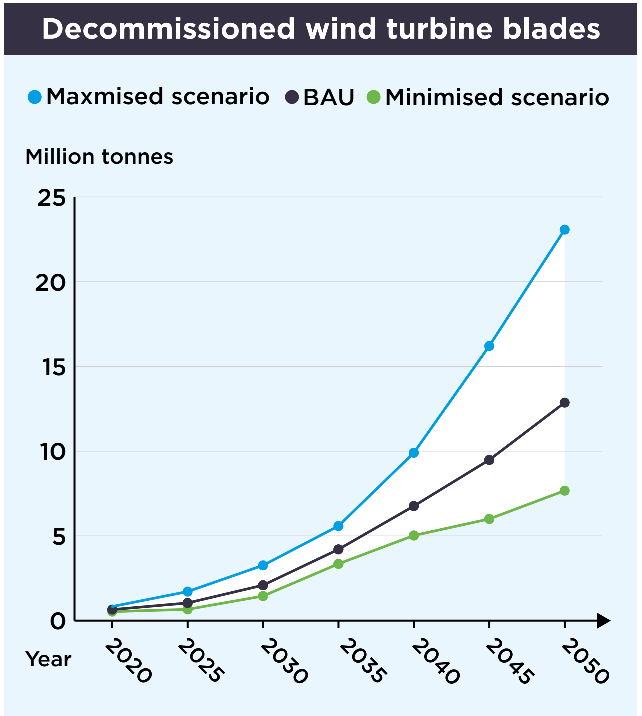
Source: IEA, 2024.

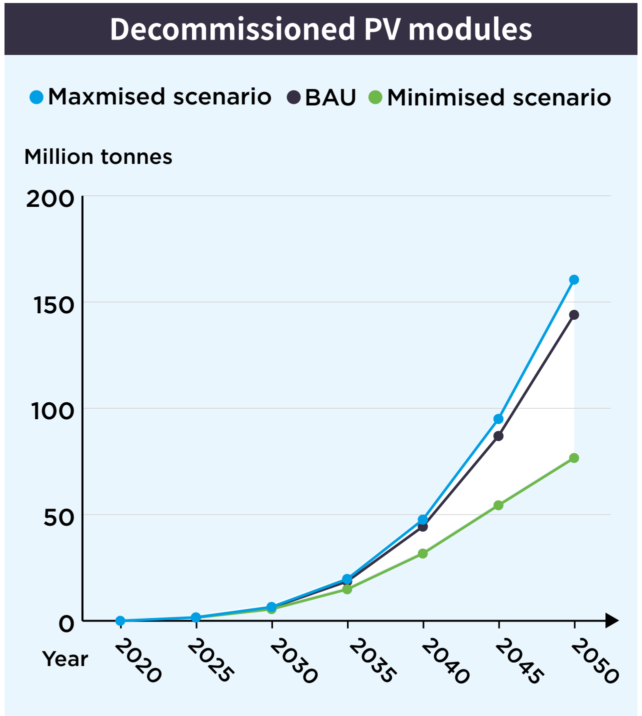
China is at the beginning of a mass decommissioning of wind turbines and photovoltaics that will generate large volumes of waste.

By 2050 it is projected that China will generate up to 23 million tonnes of wind turbine blades waste cumulatively.[59] Wind turbines typically have a 20-year lifespan, meaning those built during the large-scale deployment from 2006 are nearing the end of their service lives. Waste is generated throughout the turbine life cycle — across manufacturing, operations, maintenance, and end-of-life phases — and evolves over time. Initially, manufacturing scraps dominate, but by 2025, end-of-life waste will surge as turbines are decommissioned. To address ageing infrastructure, China's National Energy Administration promoted upgrades for turbines over 15 years old or with a capacity below 1.5 MW in 2023, accelerating early retirements and further increasing quantities of decommissioned equipment. While 90% of turbine components are easily recyclable, the blades present a challenge due to their bulky composite materials, which are difficult and costly to separate and recycle.

Between 2020 and 2050, China is projected to generate up to 88 million tonnes of discarded solar panels, with 80% occurring between 2040 and 2050.[60] Solar panels typically have a lifespan of 25 years, though they can be discarded at various stages during transportation, installation, operation, and end of life. As the efficiency of older solar panels is significantly lower than that of newer models, many power stations are actively upgrading to more efficient panels, which accelerates the generation of waste. While solar panels contain valuable materials that could be reused to create new solar cells, current recycling technologies are inefficient and rarely implemented, leading to a significant loss of resources. Moreover, PV panels often contain hazardous materials, such as lead, which can cause pollution if disposed of in landfills.

Figure 3-3: Forecast decommissioning of wind turbine blades and PV in China[68,69]





CHINA'S WIND AND PHOTOVOLTAIC VALUE CHAINS

China dominates the global supply chain for wind and PV. China's wind and PV supply chains encompass mining, mineral refining, component production, equipment assembly, operation, and waste disposal. Minerals are sourced globally, but the refining and processing are predominantly carried out in China, which refines 90% of rare earth elements and 60-70% of lithium and cobalt (see Figure 3-4). China's dominance in global manufacturing of wind turbines and PV (see Section 3.1.1) can be attributed to favourable industrial policies, access to low-cost energy and materials, and a readily available workforce.

Wind turbine manufacturing is evolving toward larger, smarter, and more customised designs, with modular and lightweighting innovations driving this transformation. As shown in Figure 3-5, turbines consist of key components such as blades, gearboxes, rotors, and generators. The blades, primarily made from non-degradable thermosetting resin-based composites, are becoming ultra-long to enhance turbine performance. This shift is further supported by smart operations, diagnostics, and big data technologies to improve efficiency. Offshore wind power is emerging as a critical direction for the future of wind energy. Offshore turbines are taller, lighter, more efficient, and equipped with larger blades to achieve higher capacity factors. However, compared to onshore wind, offshore systems require more copper and rely heavily on direct-drive permanent magnet generators, which increases demand for rare earth metals.

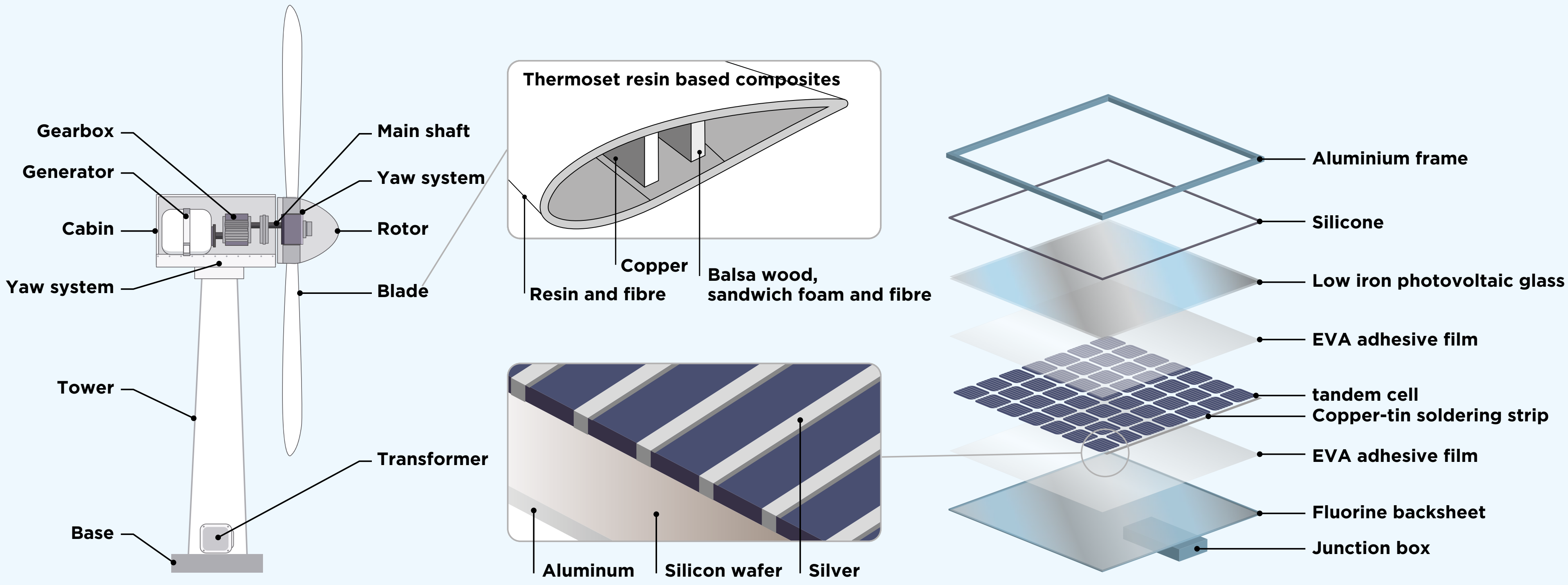
Achieving mass production of PV panels has significantly reduced costs. China's PV industry primarily uses crystalline silicon PV panels, which include components like aluminium frames, PV glass, ethylene vinyl acetate (EVA) film, fluorine backsheets, and solar cells,[61] as shown in Figure 3-5. Solar panel manufacturing, once considered high-tech, has now standardised its processes, with significant cost reductions achieved by increasing the efficiency of cells and reducing non-silicon material costs. Vertical integration is an increasingly prevalent strategy for PV manufacturers to further drive down production costs, mitigate the impacts of industry cycles, and expand into new markets.

Wind and solar farms in China require the purchase of extensive land areas, facilitated by state-owned power groups. Large-scale wind and solar projects require substantial upfront investments and long payback periods, relying heavily on policy-led incentives such as low-cost loans and cheap land. These projects are typically undertaken by large state-owned power groups in three stages: site selection and project design, construction, and operation.

Figure 3-4: Material flow of China's wind and PV supply chains

Note: The yellow highlight indicates that more than 50% of this raw material was imported in 2023.

Figure 3-5: Main components of wind turbine and crystalline silicon PV modules



3.2 Circular economy strategies can help secure the critical raw material supplies needed to support the growth of China's wind and photovoltaic industries

Circularity efforts in wind and solar have to date focused on downstream solutions, but design-led upstream opportunities will be crucial in the next phase of capacity scale-up. While recycling helps manage the decommissioning of existing stock, the rapid increase in renewable energy capacity calls for more proactive upstream circular economy measures. A comprehensive circular economy approach addresses not only waste but also material throughput. It helps mitigate supply chain risks and secure critical material supplies, which are vital for scaling up wind power and PV to meet China's ambitious climate targets. Some pioneers in China are already exploring designs for disassembly, easy transportation, durability, and recyclability, setting new standards for incorporating circularity in the manufacturing phase, and are developing product service systems (also known as third-party ownership) in the use phase.

Upstream circular economy opportunities in the wind power and PV value chains include:

Wind power value chain

Redesign

Innovative design for wind farm projects advances their circularity. The circular design of wind farm projects hinges on critical elements such as strategic site selection, smarter construction methods, and optimal material choice. Selecting sites on degraded or less productive lands minimises environmental impacts, aligning with eco-friendly land-use practices. The 'Wind+' model, which integrates wind power with various industries, unlocks new use scenarios such as offshore wind combined with marine ranching. Although these integrated technologies are in the exploratory phase and entail high investment costs, they present significant potential, warranting continued government support and strategic investment.

Case study: Integrated wind energy and marine aquaculture in Laizhou Bay, Shandong

Located in Laizhou Bay, Shandong, this innovative pilot project merges wind energy with marine aquaculture, driven by China Three Gorges New Energy. With an investment of RMB 3.6 billion and a 300 MW capacity, the facility went online in December 2022. The installation includes 50 wind turbines and a 220 kV booster station, expected to generate 940 million kWh yearly, and cut emissions by 790,000 tonnes of CO_2 compared to coal-based energy plants.

The design integrates marine ranching within 50 m of the turbines, using breeding and fish aggregating reefs to enhance local marine biodiversity. This project showcases a multi-dimensional use of maritime space and provides a potential blueprint for circular oceanic resource management.

Redesign · Reduce

Prioritising design for circularity in wind turbine systems can yield significant economic and environmental benefits throughout their life cycle. Traditionally, the focus in wind turbine design has been on maximising electricity output and minimising costs, leading to substantial material waste and logistical inefficiencies. There is an urgent need to redefine the design parameters of wind turbine systems. Design for circularity provides a transformative solution by focusing on modularity, recyclability, and high-performance materials. This includes modular design strategies, as exemplified by Goldwind's new turbine models, which are engineered for easier transport and quicker assembly on-site, reducing overall logistics costs and emissions. Additionally, Siemens Gamesa is pioneering fully recyclable wind turbine blades made from thermoplastic materials that can be recycled into new blades. Furthermore, the use of high-performance materials by companies such as Sinovel, is enhancing turbine performance by integrating high-strength materials that increase the durability of key components like rotors and towers.

Repurpose · Repair · Refurbish · Remanufacture

Circular interventions during the use phase include repurposing, maintenance, refurbishment, and remanufacturing. Some early wind turbine manufacturers in China have exited the market, leading to 'orphaned' turbines that are idle or underperforming, resulting in asset waste and economic loss. Maintenance, refurbishment, and remanufacturing can extend the lifespan of these turbines, providing significant economic and environmental benefits. For example, remanufacturing bearings reduces material use by over 80% and energy use by over 70%, cutting carbon emissions by 59%.[62] A pneumatic repair method, successfully applied to damaged blades at Ningxia Haiyuan Wind Farm, improved power generation efficiency by 20%.[63] Repowering is becoming standard practice, exemplified by the 2023 project at Dabancheng Wind Farm in Xinjiang, which replaced 155 old turbines with new 6.7 MW units, avoiding 630,000 tonnes of carbon emissions annually. Decommissioned blades with good mechanical properties, corrosion resistance, and durability can be repurposed for various applications, such as smaller wind turbines on farms, logistics parks, or urban public spaces, thereby extending their lifespan.

Recycle

Wind turbine blade recycling is still in its infancy, with significant differences in technical maturity, commercial viability, and environmental impact among the primary methods: mechanical, pyrolysis, and chemical recycling. Mechanical recycling, the most established and widely used, breaks down blades into low-value fillers; while this method is cost-effective, it limits high-value material recovery. Pyrolysis, involving high-temperature decomposition, can extract glass fibres and generate combustible gases for energy, but its high energy demand and GHG emissions pose environmental challenges, making it costly and less commercially viable. Chemical recycling, which uses solvents or catalysts to recover high-purity glass fibres for reuse in new blades, faces challenges in large-scale commercial application due to its complexity and the high cost of catalysts.

Photovoltaic value chain

Redesign

Designing effective solar farms requires strategic site selection and responsible land-use practices. Site selection should consider soil quality, vegetation, and hydrogeological conditions to ensure minimal ground disturbance and compatibility with local water resources. During construction, measures to control waste, soil disruption, and pollution are essential. In water-scarce regions, integrating PV systems with agriculture and conservation can optimise land use and promote nature-based solutions. Floating PV systems can serve as a viable alternative to land-based installations, especially in areas with high land-acquisition costs and electricity prices. These systems often perform more efficiently due to lower operating temperatures, enhanced by higher wind speeds over water.

Redesign Reduce

Circular interventions in production focus on material-efficient design and low-impact material substitutes. Trends towards larger, thinner PV cells and the coexistence of multiple cell technologies are becoming inevitable. Modular designs permit localised replacement of components, minimising material consumption and costs. Integrated encapsulation enhances product durability, ensuring resistance to wind, rain, acids, and corrosion, thereby extending lifespan. Improvements in manufacturing techniques include China's industry norms that set benchmarks for energy and water usage in silicon production, and the adoption of technologies like diamond wire cutting, which reduces CO_2 emissions by 290 kg per kW of solar panel produced compared to conventional methods.[64] Additionally, replacing aluminium frames with low-carbon alternatives such as polyurethane, steel, or recycled aluminium not only cuts emissions but can also increase corrosion resistance and improve insulation properties. However, switching to other materials requires careful consideration of their after-use pathways.

Case study: Aquaculture and Floating Solar integration in Taishan City

The 'Aquaculture and Floating Solar' model involves installing solar panels above fish ponds, utilising the shading and cooling effects of the panels to inhibit algae growth, thereby increasing aquaculture production and biodiversity. The lower ambient temperature above water bodies compared to land, combined with increased spacing between panels, creates an environment with good sunlight, ventilation, and cooling, extending the lifespan of PV modules.

In 2021, Taishan City built the largest single fish-solar integration project in the Greater Bay Area, with an installed capacity of 500 MW, providing 543 million kWh of clean electricity annually and reducing carbon emissions by about 534,000 tonnes a year compared to coal-fired power plants. Previously, the high sunlight and water temperatures limited the area to oyster farming only. After the project's completion, reduced algae growth and improved water quality created a favourable environment for higher-value fish and shrimp production. Over its 25-year operational period, the project is expected to generate CNY 1.2 billion in local tax revenue.

Reuse Repurpose Repair

Circular interventions during the use phase of solar panels, such as maintenance, reuse, repurpose and repair, are pivotal for optimising their operational efficiency and extending their service life. Regular maintenance is crucial to preserving system effectiveness and longevity as neglecting tasks such as cleaning and shading management can lead to reduced output and accelerated degradation.[65] Accumulation of dust particles on the PV surfaces significantly diminishes their power output, yet regular cleaning helps maintain optimal absorption of solar radiation. Addressing encapsulation issues through repair can enhance grounding impedance, which prolongs the lifespan of the panels and restores their power generation capacity. Innovations in on-site PV repair technologies, such as those developed by the Czech University of Life Sciences, are designed to resolve issues with encapsulation materials, restoring electrical insulation performance and extending module service life by at least five years. Furthermore, the carbon footprint of this repair technology is less than 1% — and the cost only 10% — of that associated with full panel replacement.[66] Decommissioned panels, although reduced in efficiency, can still generate electricity. Companies like Beijing Xinyuan Jingwu Technology Co., Ltd. use Colour Multilayer Technology to give waste panels new functions, such as off-grid microgrids for smart city infrastructure.

Recycle

Recycling solar panels is crucial to ensuring valuable materials stay in the economy. By 2030, global solar waste can meet 15% of silicon demand, reducing carbon emissions by about 4 million tonnes.[67] Currently, recycling technologies focus primarily on recovering bulk materials, such as silicon wafers and glass, which make up about 90% of the module's mass. These processes, while well-established, often overlook trace materials like silver, copper, and lead, which hold significant value but are present in smaller quantities. High-temperature processes are effective for bulk material recovery but risk releasing harmful emissions, particularly from fluorinated backsheets. Mechanical and solvent-based approaches, while capable of delaminating components like ethylene-vinyl acetate (EVA), tend to be either energy-intensive or hazardous. Furthermore, the variability in PV module design, including the declining use of silver and thinner silicon wafers, reduces the profitability of recovering these materials.

Table 3-1: Circular strategies and interventions in wind and solar value chains

Industry	Circular strategies	Examples of circular interventions (a non-exhaustive list)	R-Pathways
Wind power	Smarter building design and construction	Wind farm project design	Redesign
		Compostable and easily recyclable materials, reusability, easy to disassemble, modular design	Redesign
	Extending lifespan of products and components	Upgrade small turbines with larger ones (repowering)	Reuse
		Cascade use in other value chains	Repurpose
		Regular maintenance	Repair
		Refurbishment of wind turbine components	Refurbish
		Remanufacturing of wind turbines	Remanufacture
	Maximising use of discarded materials	Recycling after-use wind turbines blades	Recycle
Solar power	Smarter product design and manufacture	PV power station project design	Redesign
		Material-efficient design	Redesign
		Material substitution	Reduce
	Extending lifespan of products and components	Reuse	Reuse
		Cascade use in other value chains	Repurpose
		Regular maintenance	Repair
		Remanufacture	Remanufacture
	Maximised use of discarded materials	Material recycling	Recycle

3.3 Five main barriers hinder the integration of circular economy into China's wind and solar value chains

The manufacturing of wind turbines and solar cells is characterised more by material innovation and cost competition than circularity, with insufficient circular design awareness and expertise among key value chain actors. Currently, the design of wind and PV equipment does not fully incorporate circular principles, such as easy disassembly and recyclability. This makes waste reduction challenging from the start and creates issues when decommissioning equipment. In the case of wind turbine blades, while there is ongoing research into high-performance materials and recyclable carbon fibre, the focus remains on increasing material efficiency and manufacturing stability. Likewise, PV manufacturers prioritise maximising conversion efficiency and minimising production costs over designing for repairability and disassembly, which is made harder by the sandwich structure of PV modules.

There is a lack of clarity on how power station operators can discharge their responsibility to decommission equipment after use. The recycling of wind and solar equipment in China is still in its infancy. Although state-owned enterprises own most centralised wind and solar stations and bear disposal responsibilities — unlike in Europe, where manufacturers hold responsibility — disposal procedures remain unclear. This is particularly due to the complex process for state-owned asset disposal, hindering effective implementation. Many power station operators have since adopted a 'wait-and-see' approach, resulting in many offline equipment items being stored in warehouses or worse, left in the open, and have not yet been sent to recycling facilities. This limits the supply to such facilities and therefore their operational potential. Distributed solar users, especially households, often lack awareness of standardised recycling and resource utilisation procedures, and the responsibility for managing the waste from distributed PV panels remains unclear. Additionally, weak regulatory enforcement leads to improper disposal methods, such as landfilling and incineration, causing waste and pollution.

The geographical distribution of decommissioned wind turbines and PVs complicate after-use pathways. The uneven geographic distribution of wind and solar resources in China leads to an uneven spatial and temporal distribution of decommissioned equipment, with installations often sited in remote areas such as mountains, deserts, and offshore locations to optimise land use and have the best access to wind and sunlight. These areas have limited infrastructure, making collection for centralised disposal difficult. In 2040, five regions — Hebei, Jiangsu, Inner Mongolia, Shandong, and Xinjiang — are projected to produce about 40% of the country's decommissioned wind turbine blades. By 2050, northern regions like Inner Mongolia and Ningxia will account for around a quarter of PV waste.[70] Furthermore, the rapid growth in the installation of distributed PV systems is expected to result in approximately twice the amount of waste generated from 2030 to 2050 compared to utility-scale PV systems.[71]

There are difficulties tracking and tracing equipment after use. The sectors lack a reliable data platform capable of tracking items over space and time. Combined with multiple factors such as the early retirement of inefficient equipment and the extended lifespan of new equipment, this makes it difficult to accurately predict the scale and spatial distribution of wind and solar decommissioning. This increases the risk of lost or improperly disposed equipment. Additionally, poor coordination along supply chains — including manufacturers, component suppliers, operators, collection, and recycling companies — hinders the accurate tracking of wind and solar equipment and therefore the establishment of closed-loop supply chains. A lack of data disclosure has also prevented the development of standardised emission accounting systems, making it difficult to fully assess the economic, environmental, and social benefits of circular economy measures.

Technologies and business models for material separation and recycling are still at an early stage of development. Although recycling technologies for wind turbines and PVs are part of national R&D plans, current resources and investments remain inadequate. Key technologies like high-purity separation of solar cells, rare metal collection, composite material recycling, and high-value material utilisation face significant challenges. The lack of core separation and recycling equipment limits research and the implementation of comprehensive recycling processes. This means high-value recycling business models remain underdeveloped. Further challenges to such business models include discrepancies between equipment decommissioning sites and processing facilities, leading to high storage and transportation costs. Moreover, comprehensive recycling requires substantial fixed asset investment and ongoing operational expenditure, with current decommissioning volumes insufficient to economically sustain the continuous running of such recycling operations.

Chapter 4

The circular economy can increase China's resilience to the effects of climate change

Chapter 4

The circular economy can increase China's resilience to the effects of climate change

Climate change-induced extreme weather events and various slow-onset adverse impacts are intensifying, strengthening the global consensus that climate adaptation action is a necessity. China, located in a globally climate-sensitive area with generally fragile ecological environments, faces increasing threats to its economic and social development. In May 2022, China's Central Government released the 'National Climate Change Adaptation Strategy 2035', which emphasises the need to balance mitigation and adaptation efforts, strengthen the climate resilience of natural ecosystems and economic and social systems, and effectively respond to the adverse impacts and risks of climate change. Although the link between the circular economy and climate adaptation has not been fully explored,[72] studies confirm that the circular economy has the potential to generate positive benefits in climate adaptation.[73]

Circular economy can enhance supply chain resilience by increasing the geographical distribution of raw material supplies. The circular economy can significantly reduce demand for virgin raw materials and potentially enhance supply chain resilience. Sources of materials in a circular economy are more diverse and flexible since they draw increasingly on products already in the economy, returned from geographically dispersed customers rather than from point-sources of raw materials like mines. This can spread risks of climate-related disruptions to materials supplies more widely, increasing the resilience of supply chains. Balancing this local reuse of materials, and the associated reverse logistics, with sourcing raw materials from further afield is needed to ensure overall vulnerability to climate disruptions is not increased.[74]

As an example, the potential to increase resilience through circular supply chain actions in the global renewable energy sector could be substantial. By 2040, recycling retired batteries could supply 60% of global demand for cobalt, 53% for lithium, 57% for manganese, and 53% for nickel.[75] By 2050, 20% of the US wind industry's projected demand of 15,500 tonnes of rare earth elements could be supplied from retired wind turbines.[76] In China, the wind industry's cumulative demand for rare earths from 2021-2060 is projected to be 222,000-430,000 tonnes, with about one-third able to be sourced from recycled wind turbines.[77] The benefits of a circular economy that prioritises inner loops as well as incorporating recycling will be even larger.

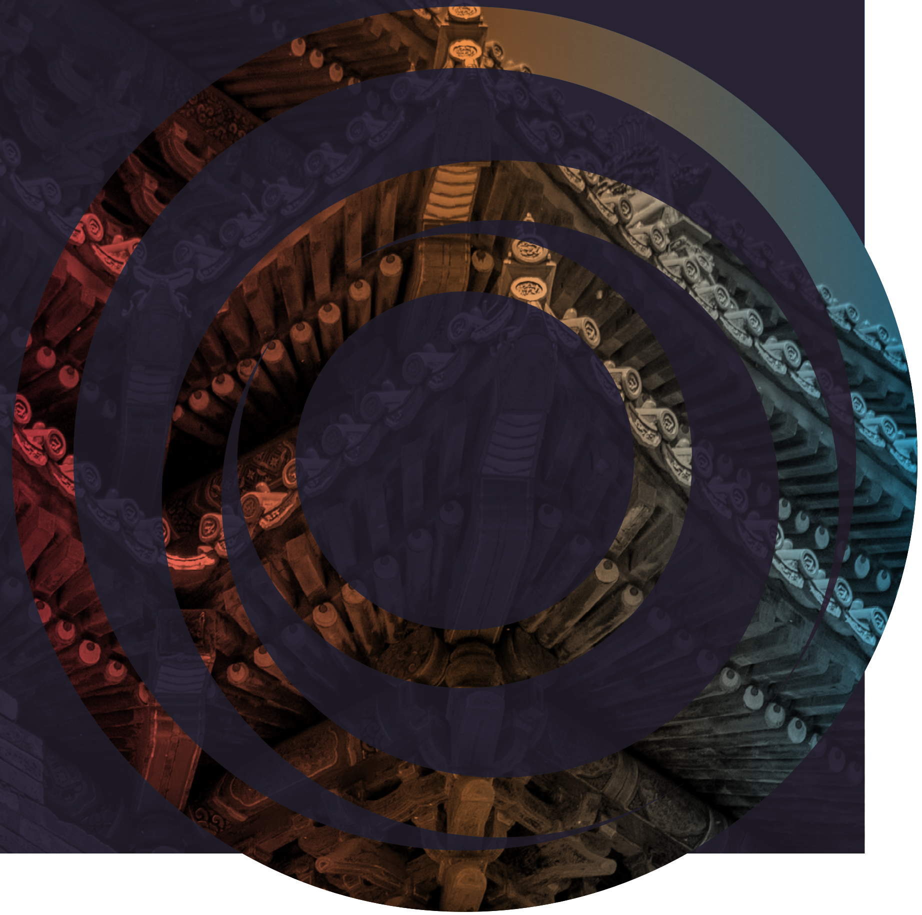
By regenerating nature, the circular economy increases the resilience of people and the economy to the effects of climate change. The importance of nature to the economy is illustrated by two central truths. The first is that more than half the world's GDP relies on nature[78] and, in the Eurozone, 72% of businesses are highly dependent on at least one ecosystem service (agriculture being only the most obvious).[79] The second is that healthy ecosystems tend to be more resilient in the face of storms, floods, and fires, thereby enhancing their ability to adapt to the impacts of climate change.[80] Regenerating nature therefore not only supports the underpinnings of the economy, but also increases its resilience. The benefits can be illustrated in both urban and rural settings.

Maximising nature in cities increases the resilience of businesses and citizens to the effects of climate change. According to the Ellen MacArthur Foundation's recently published report *Building Prosperity: Unlocking the potential of a nature-positive circular economy for Europe*, expanding green spaces can reduce urban peak temperature by 1-3°C, and introducing more permeable surfaces can reduce flood intensity by 10-20% by slowing water flows and increasing infiltration. The latter would also help recharge groundwater aquifers and therefore increase resilience to future droughts. Studies show that nature-based solutions such as sustainable urban drainage systems, living walls, and green roofs are more cost-effective than hard infrastructure at building resilience to the intensifying impacts of climate change.[81]

Applying regenerative practices in agriculture can improve the resilience of food supply. Such practices enhance soil health, biodiversity, and overall ecosystem quality. Methods like minimum tilling, cover cropping, and integrated pest management mimic natural ecosystems, foster biodiversity, and reduce the need for synthetic inputs. This approach helps create healthy soils that better absorb and retain water, increasing their resilience to drought and flood.[82] In China, policies and grassroots initiatives are supporting such practices. Key government efforts include the 'Zero Growth of Fertiliser Use Policy', initiated in 2015, and the promotion of conservation tillage, particularly in the black soil region of northeastern China. The 'Conservation Tillage Action Plan' aims to prevent the erosion of soil and restore its quality by increasing its levels of organic matter. Conservation tillage practices have already been successful in improving soil health and promise significant further gains over time.[83]

Chapter 5

Calls to action: Advancing circular economy for climate action in China



Chapter 5

Calls to action: Advancing circular economy for climate action in China

In the critical journey toward a net-zero future, China is making fast progress and is demonstrating a firm commitment to climate stewardship, with the circular economy playing a pivotal role. For China this shift is not just an option but a necessity for achieving its ambitious climate goals, and decoupling economic growth from carbon emissions and finite virgin material inputs. Using the Ellen MacArthur Foundation's Universal Policy Goals (UPG) framework,[84] this chapter presents a set of targeted actions designed to accelerate the integration of a holistic circular economy into China's climate agenda.

Table 5-1: **Universal Policy Goals framework for circular economy integration into China's climate action**

Goal 1: Stimulate design for the circular economy

- Develop circular product-specific policies
- Promote circular urban planning
- Redesign renewable energy supply chains

Goal 2: Manage resources to preserve value

- Reshape consumption patterns to adopt circular behaviours
- Implement mandatory fee-based EPR schemes
- Harmonise waste management legislation

Goal 3: Make the economics work

- Align taxation with circular economy outcomes
- Leverage public procurement to create demand for circular economy initiatives
- Support MSMEs and informal sectors in the circular transition

Goal 4: Invest in innovation, infrastructure, and skills

- Fund circular economy research, development, and innovation
- Invest in circular economy infrastructure
- Build a strong circular economy reporting and measurement system

Goal 5: Collaborate for system change

- Stimulate cross-value chain collaboration through eco-industrial parks
- Engage in collaborative research on the potential for the circular economy to tackle climate mitigation and adaptation simultaneously
- Promote international cooperation

5.1 Stimulate design for the circular economy

Designing for the circular economy is a critical enabler for addressing climate change. The design phase sets the foundation for how products, services, and systems function throughout their life cycles, directly influencing resource use and emissions. Early circular design choices — such as designing for material efficiency, substituting material, or enabling reuse — influence product life-cycle emissions and end-of-life fate. By embedding circular principles at the outset, industries can lower energy demand and material consumption, both of which are key to mitigating climate impacts. Once these design decisions are made, they are difficult to reverse, making it essential to prioritise circularity to achieve climate goals.

In China, where shifts in both production and consumption are rapidly occurring, circular design takes on added importance. China is the world's largest manufacturing hub, and home to a rapidly expanding consumer market. Its implementation of circular design across products, processes, and supply chains would therefore have far-reaching global effects. China's thriving digital technology sector provides a unique advantage in this shift since digital tools can help with modular design, material selection, and product redesign. By embedding circular principles at the core of its industrial and urban systems, China can reduce waste, improve resource efficiency, and extend product life cycles, all while meeting its ambitious climate goals.

Actions 1:
Develop circular product-specific policies

To foster a circular economy, legislation mandating the integration of circular principles into product design is highly desirable, with priority given to material-efficient design and the use of low-impact materials. Material substitution can also be supported through refined product standards and policies that encourage the use of recycled content. Drawing inspiration from initiatives like the EU's 'Ecodesign for Sustainable Products Regulation' (ESPR), such policies could significantly enhance product circularity through improved eco-design and transparent life-cycle management. Starting with a list of high-carbon and material-intensive products such as buildings, vehicles, and renewable energy equipment can be a good approach.

Establishing a robust labelling system for circular and low-carbon products is a specific policy measure in this area. By leveraging examples such as energy efficiency labelling, these measures aim to minimise the carbon and ecological footprints of products, guiding consumers towards more environmentally conscious choices.

Actions 2:
Promote circular urban planning

Cities are at the forefront of China's efforts to meet its climate targets, contributing about 85% of the nation's carbon emissions.[85] As China aims to increase its urbanisation rate from 64% in 2020 to 75% by 2050, the 'National New Urbanisation Plan' (2021-2035) provides a blueprint for future urban growth, where economic, social, and ecological objectives are integrated. To realise this vision, city planners can embed circular economy principles into every facet of urban planning, from the development of new cities to the upgrade and maintenance of existing ones.

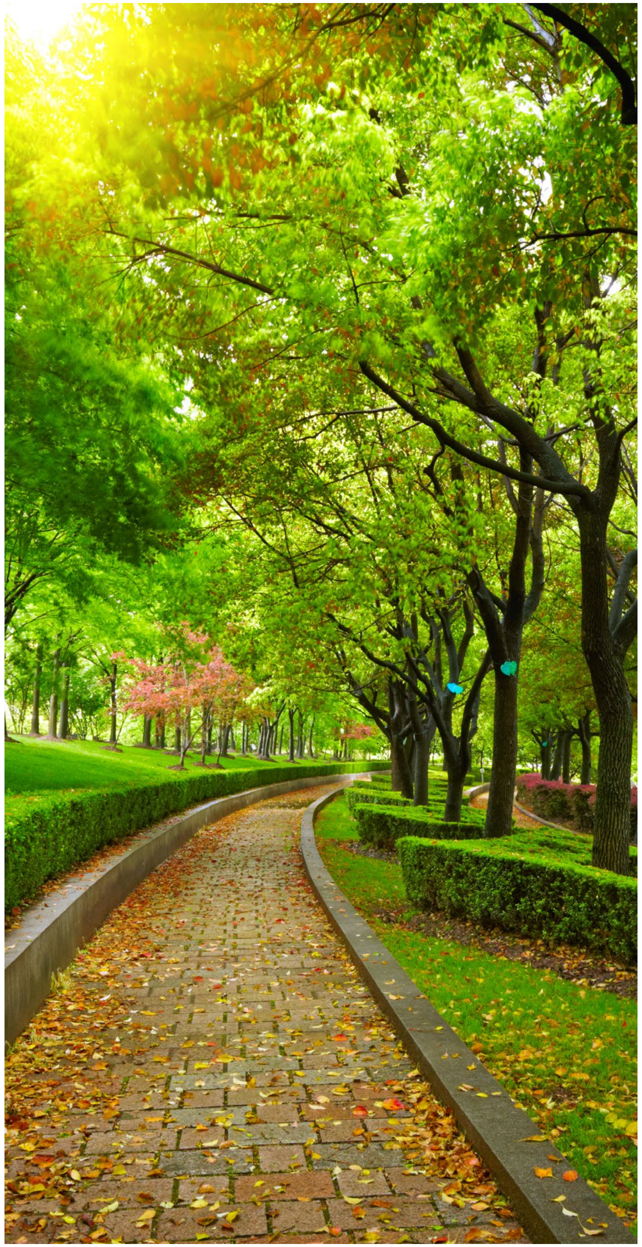
City-level initiatives like 'zero-waste cities', focused on waste reduction, 'low-carbon cities', aimed at lowering GHG emissions, the '15-minute city' model, which promotes access to essential services within a short walk or bike ride, are aligned with a circular transition. However, these initiatives benefit from harmonised implementation, guided by a unified set of circular economy criteria that influence spatial planning, land allocation, architectural design, construction, and transportation systems. Beyond infrastructure, urban planning will also shape the daily lifestyle choices of residents — how they consume, live, and travel. City planners, developers, and asset operators could leverage emerging technologies such as the IoT, cloud computing, and AI, alongside the sharing economy, to create real-time resource monitoring networks that enhance resource use, reduce waste, and accelerate the transition to a circular urban future.

Actions 3:
Redesign renewable energy supply chains

Moving beyond policies and practices that focus primarily on recycling will be needed to enable the effective redesign of renewable energy supply chains. While recycling decommissioned equipment is an essential part of preventing waste from ending up in landfills or being incinerated, exploring other circular opportunities has the potential to create much more value, which a few key policy interventions could help realise.

China could actively participate in or establish its own Responsible Mining Initiatives to secure ethical sourcing of critical raw materials while ensuring that their supply is sufficiently diversified to reduce dependence on a few regions and promote global collaboration. Additionally, optimised land use and integration with other industries should guide the planning and deployment of renewable energy projects, ensuring that land allocation for wind and solar installations does not compromise ecological or agricultural priorities. A comprehensive land allocation strategy is crucial to balancing infrastructure growth with regenerating natural systems, particularly for large-scale projects like solar parks and wind farms.

The government could assess and strategically promote innovative models such as 'Wind+' and 'Solar+', which integrate renewable energy projects with agriculture, aquaculture, and other land-use practices, creating multifunctional landscapes that maximise land-use effectiveness. Finally, cross-sector collaboration is essential for strengthening supply chain transparency, with stakeholders across industries working together to improve traceability and governance.



5.2 Manage resources to preserve value

Where Goal 1 of the UPG supports the transition to circular designs, production, and business models, Goal 2 focuses on developing a rich system of resource management to keep goods and materials in productive use at their highest value. China stands as the world's leading manufacturing hub and the largest consumer of raw materials, with 2022 raw material consumption reaching 28.5 Gt — nearly one-third of the global total.[86] Transitioning from conventional waste management to a comprehensive model of resource stewardship is essential for the nation's future. Since 1990, China has doubled its resource productivity, driven by targeted policies addressing environmental challenges like urban air and water pollution and waste management.[87] Much of this success can be credited to capitalising on 'low-hanging fruits' of continuous efficiency improvements in production processes.

However, many more opportunities remain. The recent green transition policy targets a further 45% increase in primary resource productivity by 2030 compared to 2020. To meet this goal, China can look beyond efficiency towards embedding circular economy activities across sectors. By extending product lifetimes and circulating materials, such activities, which include reuse and remanufacture for example, preserve value in the form of embodied energy, labour, materials, and carbon. Implementing a sufficiency approach on the demand side by promoting circular consumption patterns, and enhancing waste management systems are complementary to these activities. Such a combination of actions would not only support China's climate action but also enhance supply chain resilience, reducing reliance on imported resources and improving the nation's overall resource security. These benefits would reinforce China's stature in the global economic arena, helping ensure its manufacturing sector remains robust and competitive.

Actions 4:
Reshape consumption patterns to adopt circular behaviours

Profound changes in consumption patterns and lifestyles are feasible. Societal wealth and well-being can be measured in stocks instead of flows, in capital instead of sales. Traditional Chinese values, such as 'xiaokang', emphasise spiritual fulfilment and sufficiency, highlighting the importance of natural capital and ecosystem services. Transitioning to circular consumption can be achieved by adopting a comprehensive A-S-I approach that combines avoiding over-production and consumption by limiting unnecessary demand, *shifting* demand through sharing and repairing instead of buying new, and *improving* efficiency through technological innovation and substitution.[88]

Governments play a crucial role in enacting legislative measures that provide consumers with information about product circularity. They can also focus on awareness-raising campaigns and implementing landmark policies that promote circular consumption and accelerate the adoption of circular consumption behaviours. Pilot projects could include office space sharing, clothes rental platforms, car-free zones, and bans on single-use plastics. Governments and businesses alike can mainstream the transition to circular business models. This includes incorporating hidden environmental and social costs into product pricing, driving changes in market structures, fostering consumer engagement, and adapting corporate governance.[89] Businesses could apply nudging techniques via marketing campaigns, a concept from behavioural sciences, to increase the uptake of circular behaviours among consumers. For example, Meituan, a leading food delivery platform in China, implemented a feature that prompts users to choose 'non-disposable tableware' when placing orders, gently nudging them toward reducing waste.

Actions 5:
Implement mandatory fee-based Extended Producer Responsibility schemes

Governments can introduce Extended Producer Responsibility (EPR) frameworks to ensure producers have accountability for their products' end-of-life pathways, and to encourage circular design and business models. Circulating products involves processes including collection, sorting, reuse, and recycling. However, at present these processes often come at a net cost for most items compared to linear alternatives. EPR schemes can help to ensure that there is dedicated, ongoing, and sufficient funding to cover that cost. Without such funding mechanisms, it is unlikely that collection, sorting, and recycling will scale to the extent required.[90] EPR places responsibility on producers for the collection and recirculation of their products when these are discarded by citizens. If designed well, EPR significantly improves the cost-revenue dynamics for reuse, repair, and recycling of discarded products. It also delivers transparency and traceability of material flows and helps attract capital investments in the infrastructure needed for large-scale reuse and recycling programmes. By bearing the costs of post-life product management, brands are encouraged to make circular design choices at the outset.

When applying EPR schemes in China, local contexts must be taken into account. While EPR is widely acknowledged as a promising tool, its effectiveness is often hindered by misapplication. A two-step approach of designing EPR schemes could be considered. The first is to forge a regulatory framework through legislative efforts, further refined by product-specific measures based on comprehensive impact assessments. The second is to create a detailed implementation catalogue that prioritises product categories according to materiality and technical recyclability. Such a list might include, but not be limited to, plastic packaging, electrical goods, textiles, and renewable energy equipment.

Box 2: EPR for renewable energy equipment

In China, the asset owner — also the electricity producer — is held accountable for the end-of-life management of decommissioned wind and solar equipment, contrasting with Europe's model where equipment manufacturers hold this responsibility. The distinction is understandable given that wind and solar farms in China are predominantly operated by a small number of large state-owned enterprises, which possess the necessary resources and capabilities to take on the responsibility. Nonetheless, joint efforts are needed by the State-owned Assets Supervision and Administration Commission (SASAC) and other relevant departments to establish product residual value assessment guidelines and decommissioning standards that support the collection and recycling of energy equipment at the end of its useful life.

Actions 6:
Harmonise waste management legislation

Waste legislation is a key determinant of the pathways of goods and materials after use. Resource classifications can enable or hinder activities related to reuse, repair, remanufacture, and recycling. Unblocking this issue in current waste legislation can bring economic and environmental benefits by keeping materials in the economy. It can also bring societal benefits through the creation of jobs across all skill levels and sectors, from design to resource management.

The current regulatory framework for waste management in China does not sufficiently emphasise the waste hierarchy, sometimes leading to practical challenges in waste treatment. For example, recyclers find themselves in competition with incinerators (for energy recovery) for the supply of discarded materials. There is an opportunity for legislative bodies to enhance coordination between laws related to waste management, which include the Circular Economy Promotion Law, the Cleaner Production Promotion Law, the Solid Waste Pollution Environment Prevention Law, and the Anti-Food Waste Law. A strategic revision of the Circular Economy Promotion Law could reinforce its role as framework legislation in fostering improved approaches to waste management. This would involve clearly defining a waste hierarchy following the 10R framework set out in this paper and then crafting and refining specific regulations and guidelines contextualised for sectors including buildings, vehicles, white goods, and renewable energy equipment.

5.3 Make the economics work

Current economic policies, deeply rooted in a linear model of material consumption, could be shifted strategically towards circular economy principles to foster long-term economic resilience and the advent of an ecological civilisation. Such a transition would echo China's efforts to integrate environmental stewardship into its socio-economic development plans. Economic policies play a critical role in shaping organisational behaviour. Without this crucial shift, the potential for circular and low-carbon transition risks being undermined.

To support the development of the resource flows that are the focus of Goals 1 and 2, Goal 3 focuses on creating the economic conditions needed to scale circular outcomes. This includes updating fiscal and trade policies, leveraging public finance, adjusting subsidies, and prioritising circular criteria in public procurement. Collaboration with key sectors like finance and digital technology is essential to create regulations that encourage investments in circular innovations.

Actions 7:
Align taxation with circular economy outcomes

A key step in advancing circular economy outcomes is reforming the tax system to shift the focus from taxing renewable resources, including human labour, to taxing non-renewable resource consumption. Implementing a landfill tax, for example, raises the cost of waste disposal, pushing industries to reduce waste and increase recycling. Sweden's Landfill Tax, introduced in 2000, has proven highly effective, significantly reducing the amount of waste sent to landfill. Combined with a ban on certain types of waste, this tax could significantly increase recycling rates and reduce GHG emissions from waste management. Additionally, a material input tax can discourage the use of virgin materials and encourage companies to incorporate recycled content into production. An example of this is the UK's Plastic Packaging Tax, which taxes packaging that contains less than 30% recycled content.

Value-added tax (VAT) could be applied to activities that can encourage the linear use of resources, such as mining and resource-intensive manufacturing. By contrast, activities that circulate materials, such as reuse, repair, remanufacturing, and recycling could be exempt from VAT.

China introduced a carbon market in the form of an emissions trading system (ETS) in 2021. Carbon credits could reward businesses not just for reducing emissions but also for preventing them. For instance, companies that invest in Product-as-a-Service (PaaS) models, where they retain ownership of products and offer them on a subscription basis, could avoid future emissions by extending product lifespans and reducing the demand for new production.

Actions 8:
Leverage public procurement to create demand for circular economy initiatives

Government procurement can be transformed into a powerful lever to stimulate demand for circular products and services by integrating circular economy principles into procurement systems. This includes consistently updating procurement guidelines to prioritise the purchase of products that meet circular and low-carbon criteria. For example, the 'Notice on Expanding Government Procurement to Support Green Building Materials and Promote Building Quality Improvement' introduces pilot programmes in selected cities that promote the use of reusable, high-strength, durable, and recyclable materials in public building projects.

By adopting these strategic procurement policies, government entities can set elevated standards for circularity, sending a clear market signal that encourages businesses to align their product portfolios with circular economy principles. This not only drives demand for circular products but also fosters innovation and accelerates industry-wide transformation.

Actions 9:
Support MSMEs and informal sectors in the circular transition

Micro-, Small-, and Medium-sized Enterprises (MSMEs), which make up 98.5% of China's businesses, contribute 60% of the country's GDP and 75% of its employment.[91] However, many MSMEs face significant challenges in adopting circular practices due to limited resources and capabilities. Policy interventions could focus on boosting industrial clusters to enable MSMEs to form eco-industrial networks where one company's waste or by-product serves as another's raw material. This enhances circularity across industries and fosters the creation of new business opportunities.

Access to finance remains one of the most critical barriers for MSMEs in China. To enable the transition to circularity, a diverse range of flexible financial mechanisms is necessary, including public investments, blended finance models, demand-led financing, and targeted loan schemes.

Workers in the informal sector contribute significantly to China's economy and rely on circular activities for their livelihoods (e.g. reusing, repairing, recycling, and waste-picking). Despite their valuable contribution, recognition of their role remains limited and they face health, social, and economic challenges. Supportive policies can foster better integration of informal sector workers and reduce the stigma around their role. These can include supporting the formation of cooperatives, associations or community-based organisations, and fostering closer cooperation between municipalities and local communities to simultaneously improve waste management, employment, and working conditions. Additionally, EPR systems that channel funding into waste collection and processing could be designed in ways that ensure that informal workers benefit from the transition to a circular economy.

5.4 Invest in innovation, infrastructure, and skills

Leveraging public and private finance capabilities to foster investment in innovation, infrastructure, and skills is crucial for advancing circular economy initiatives. Although many circular economy goods and services are already in development, there is still a significant need for innovation in materials, production, and delivery models. Items like multi-material packaging, blended fabrics, and composite materials are often not designed for disassembly and cannot yet be composted, recycled, or remanufactured in an economically viable manner. To change this situation, upfront investments in infrastructure, as well as ongoing operational and maintenance costs, are often high and the opportunities for private finance can be unclear. There is also a need to build skills and knowledge for workers in existing jobs across sectors from agriculture to construction and durable goods, including in MSMEs. Government can therefore play an important role in guiding innovation, infrastructure and skill development.

To effectively advance the circular economy, it is crucial to leverage China's latest initiatives focused on developing 'new-quality productive forces',[vii] alongside large-scale equipment upgrades and consumer goods trade-in programmes. State-funded research and innovation have historically paved the way for major technological advancements, such as the internet and renewable energy technologies. Similarly, the public sector plays a vital role in unlocking funding for circular economy infrastructure by attracting private investment through public finance, making long-term material innovation projects investable, and developing skills to ensure an inclusive transition to the circular economy.

These investments not only facilitate the design and introduction of circular products and systems (under Goal 1) but also support the development of efficient resource management systems (under Goal 2).

Actions 10:
Fund circular economy research, development, and innovation

To accelerate China's transition to a circular and low-carbon economy, targeted resources can be allocated to breakthrough circular technologies. Funding can be prioritised for R&D efforts that advance technologies that enhance industrial efficiency and maximise resource utilisation, such as non-destructive testing, additive manufacturing, and flexible processing. Cutting-edge digital tools like AI, IoT, and Big Data can also be leveraged to improve resource management through predictive maintenance and traceability.

It is important to support the development of key decarbonisation technologies in material science, including bio-based composites, compostable plastics, and advanced recycling of critical metals from solar panels and wind turbine blades. Innovations that are economically viable for large-scale deployment are the highest priority. Investing in specialised recycling technologies that handle various types of materials, with a focus on bulk waste management solutions, is also valuable.

Vii 'New quality productive forces' is related to innovation-led development that creates a break with traditional economic growth models and development pathways that results in a high level of technology, efficiency, and quality as well as an in-depth transformation and upgrading of industry.

Actions 11:
Invest in circular economy infrastructure

Strategic investments in resource management infrastructure are critical to building a circular economy that efficiently handles both organic and inorganic materials. Prioritising the development of digital sharing platforms, repair and refurbishment centres, and logistics and recycling facilities can support key sectors such as renewable energy, mobility, water management, waste processing, and agriculture. Integrating technologies like anaerobic digesters, EV charging stations, and microgrids help ensure these systems are scalable — able to meet local, regional, and national needs.

Governments can incentivise public-private partnerships through co-funding and direct investments in areas such as sharing platforms, reverse logistics, decentralised collection systems, and recycling plants. Successful models, like the Luhai Environmental Co. and Xiamen Municipal Government partnership, demonstrate the potential for integrated solutions that also offer education and training. To maximise impact, investments could be focused on developing circular economy facilities within major urban clusters, including the Yangtze River Delta and the Guangdong-Hong Kong-Macao Greater Bay Area.

Actions 12:
Build a strong circular economy reporting and measurement system

To allocate capital flows away from the linear economy and towards the circular economy, investors need data on which economic activities address global challenges, and which companies are taking action and making progress. Circular economy measurement and reporting also plays a powerful role in generating data and insights, identifying risks and opportunities, demonstrating impacts, informing strategic direction, and enabling the evaluation of performance and progress.

Such data allows companies to assess how well they are doing in specific aspects of the circular economy, or in specific geographies, and track their progress year on year. Tracking provides a feedback loop for ongoing strategy refinement as circular economy practices are innovated, piloted, and scaled. Tracking also helps companies gain a competitive advantage in the market by showcasing leadership amidst rising regulatory pressures and customer demands for greater transparency.

Establishing a robust modelling and data protocol is essential for ensuring data availability, comparability, and quality across sectors. For publicly listed companies, adopting a unified accounting framework is crucial to ensure that the reporting on circular economy progress is transparent and consistent.

Box 3: Improving climate emissions accounting for circular economy activity

The way GHG emissions are currently reported can disincentivise companies from shifting to circular business models or adopting circular practices. This needs to change because the circular economy transition is not only needed to address emissions, but other global challenges too, such as biodiversity loss, pollution, and resource scarcity.

The GHG Protocol, the world's most widely used emissions accounting framework, is undergoing revisions. In an effort to ensure that emissions accounting for circular activities is accurate and fair, the Ellen MacArthur Foundation worked with companies leading the circular economy transition to capture the reporting challenges they face. The research found that current methodologies can lead to inaccurate or incomplete emissions calculations, or unfairly favour linear over circular activities.

In 2025, the Foundation will publish a paper about these challenges and use the insights to inform the forthcoming revisions to the GHG Protocol. The GHG Protocol anticipates releasing draft standards/guidance for public consultation in 2025 and publishing final standards/guidance in the latter half of 2026.

The review offers an opportunity for the standards and guidance to better support companies in their efforts to more accurately attribute emissions to circular activities. Given the wide reach of the GHG Protocol, this will help to normalise the use of circular economy solutions.

5.5 Collaborate for systems change

Transforming to the circular economy in China mandates unwavering collaboration across diverse stakeholders and sectors. Achieving the transition requires a united effort among public, private, and civil sectors, breaking down silos to foster innovation in both technological advancements and policymaking.

In China, where ongoing industrialisation and urbanisation present unique challenges and opportunities, a government-led, market-driven approach could be the best course of action. The coordination of circular economy and decarbonisation efforts in China would benefit from the involvement of numerous ministries and the National Development and Reform Commission (NDRC) could play a central oversight role. Ministries responsible for the environment, finance, transport, agriculture, education, and others could all play vital roles in driving the transition. The alignment of legal norms, policy support, and technological innovations can create a powerful enabling environment. Engaging multiple stakeholders — from government agencies to local communities — can enhance collective problem solving and resource sharing, while public participation can drive grassroots initiatives. China could also take a leading role in integrating the circular economy into global climate diplomacy and putting it on the agenda of international forums.

Actions 13:
Stimulate cross-value chain collaboration through eco-industrial parks

China has a unique opportunity to enhance value chain cooperation through its industrial parks, which contribute over 50% of the nation's industrial output and 30% of its carbon emissions.[92] While these parks are significant generators of waste and GHGs, they also present vital opportunities for a circular transition. Industrial parks provide a strong foundation for cross-value chain collaboration, with several already serving as good examples. China can scale up these practices by leveraging existing pilot initiatives such as 'National Demonstrative Eco-Industrial Parks', 'Circular Transformation of Industrial Parks', and 'National Low-Carbon Industrial Parks'.

To facilitate this transition, key measures could include: mapping material and energy exchanges through digital tools; conducting life-cycle environmental impact assessments; implementing measures to reduce carbon emissions aligned with the 10R principles outlined in this paper; and putting in place innovative institutional mechanisms that create replicable and scalable models.

Actions 14:
Engage in collaborative research on the potential for the circular economy to tackle climate mitigation and adaptation simultaneously

To maximise the synergies between the circular economy and climate goals, China's policy framework can prioritise bridging evidence gaps. This includes generating robust data on the extent to which circular practices like modular design, reuse, and recycling can enhance climate resilience while reducing emissions. Policymakers should promote pilot projects across key sectors, supported by monitoring frameworks to track both mitigation and adaptation outcomes. By fostering research partnerships among government, academia, and industry, China can ensure circular economy strategies are scaled with evidence-based insights, driving comprehensive climate action.

Equally important is managing potential trade-offs between mitigation and adaptation. For example, making cities more compact enables more productive use of resources, but also concentrates assets geographically and so could make cities more vulnerable to localised climate disruptions. Taking a multidimensional approach to determine the net resilience effect of circular economy opportunities has advantages. It could mean balancing the local reuse of products and materials with sourcing them from further afield, and balancing the greater costs and complexity of distributed supply chains with their resilience benefits. To address these potential trade-offs, policies could integrate scenario planning to identify and address them early on.

Actions 15:
Promote international cooperation

Leading global initiatives on circular economy and climate can take different forms. When it comes to bilateral collaboration, China could leverage the frameworks established by the *China-EU Memorandum of Understanding (MoU) on Circular Economy and the China-US Sunnylands Statement on Enhancing Cooperation to Address the Climate Crisis*. Concrete actions could include organising dedicated workshops on integrating a circular economy to address the climate crisis. Such sessions could include sharing China's experiences and lessons learned in developing a circular economy and gathering insights from global best practices. Government officials, industry representatives, and thought leaders could be invited to contribute to the discourse.

On the multilateral front, China could drive global progress through strategic initiatives like the Belt and Road Initiative (BRI) and its active participation in international forums such as the G20 and the UNFCCC. The BRI could prioritise providing circular, renewable solutions under its South-South cooperation mechanism. Under the UNFCCC framework, China could champion enhanced Nationally Determined Contributions (NDCs) that integrate the circular economy as a solutions framework for climate change. By committing to exceed its targets and advance circular economy efforts, China can galvanise international momentum toward achieving climate goals.

Box 4: Integrating circular economy in China's NDCs

As part of the Paris Agreement, 89 countries, representing 46% of the signatories, have committed to integrating circular economy strategies in their Nationally Determined Contributions (NDCs).[viii] China's NDC includes circular economy strategies that focus on agriculture, industrial practices, and waste management. To maximise the potential for reducing GHG emissions, China could adopt more holistic circular economy strategies.

Following the Global Stocktake outcomes at COP28, countries are encouraged to submit updated NDCs before COP30 in 2025, with revised 2030 targets and new goals for 2035. China can enhance its circular economy ambitions by drawing inspiration from nations like the European Union, the Netherlands, Finland, and Chile, which have successfully integrated circular economy principles into their climate policies. Using tools and guidelines from international bodies such as UNDP, and UNFCCC can provide structured approaches to implementing systemic circular economy strategies. Organising capacity-building workshops with circular economy and climate experts would further support these efforts.

Viii Ellen MacArthur Foundation analysis based on United Nations Framework Convention on Climate Change, NDCs.

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Disclaimer

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