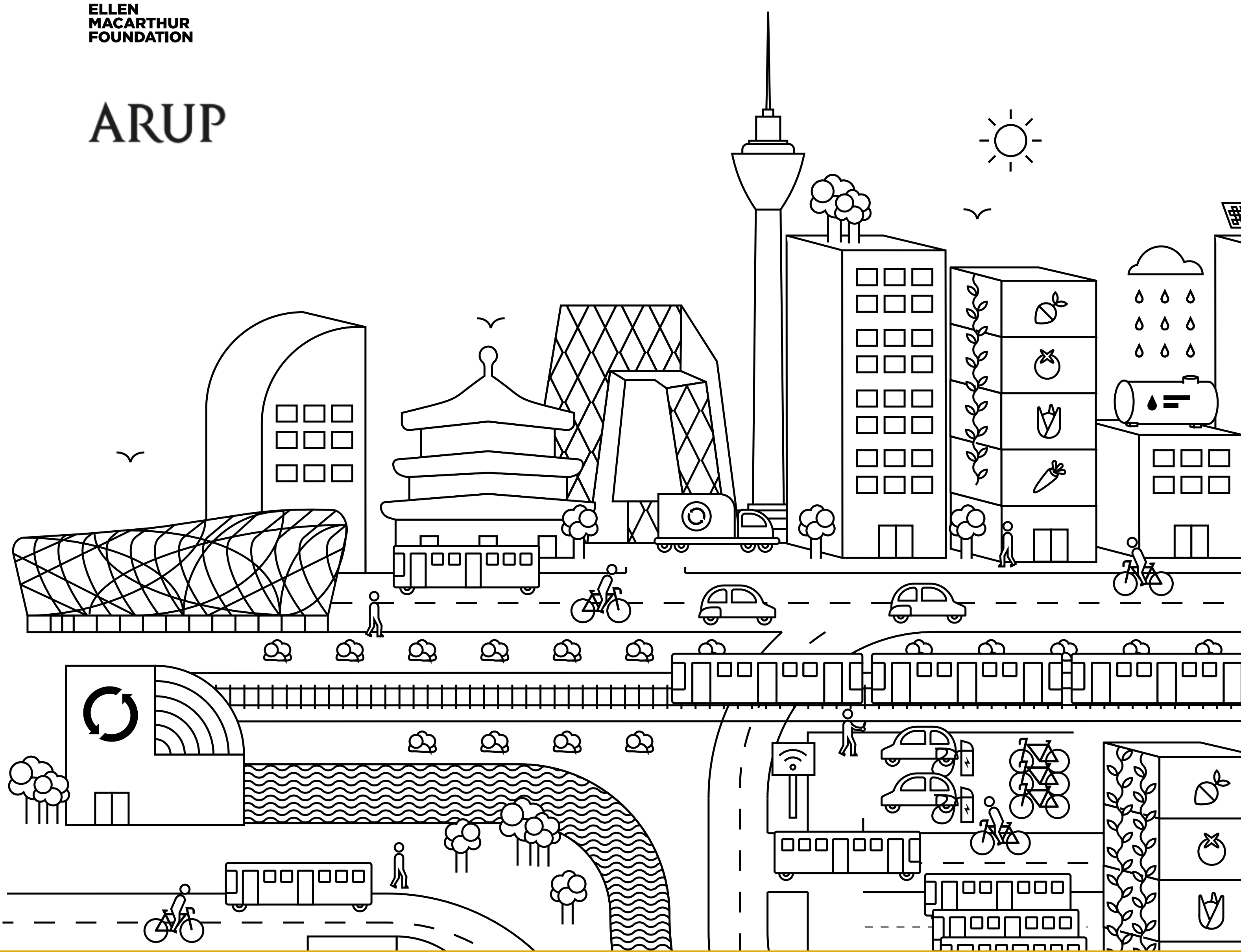
THE CIRCULAR ECONOMY OPPORTUNITY FOR URBAN & INDUSTRIAL INNOVATION IN CHINA

ELLEN MACARTHUR FOUNDATION

ARUP



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PREFACE

Throughout their history, China's cities have been important centres of ground-breaking ideas in technology and urban planning. Established in the early Ming dynasty, Beijing's originally square urban form drew on the teachings of the Kaogong Ji, a Confucian text dating from the fifth century BC that provided guidance on the size, orientation, and shape of cities, which it deemed should be designed as direct representations of the cosmos.

Today, China is again home to some of the largest cities in the world, playing leading roles in the global economy. It is tempting to hold on to recent images, embedded in the collective psyche, of these metropolises as thriving epicentres of economic dynamism while at the same time facing significant environmental challenges as a result of industrialisation. These characteristics are still very much in evidence, and this report acknowledges them and offers a range of systematic remedies. However, one of its conclusions is that China's cities are showing signs that they are already on their way to regaining their mantle as innovation hubs. For example, in China the volume of mobile payments far exceeds those of the US, and its sharing economy is projected to account for over 10% of GDP by 2020. Indeed, in the broad sweep of history, it is to be hoped that the period of industrial catch-up in China will be a mere blip on the way towards a positive and resilient model of growth.

This report offers a lens through which to view and act upon this goal for urban China's future. It offers a framework that harnesses the heritage of innovative and systemic thinking in China, and applies it to a broad conception of a circular economy, one that can redefine economic value generation in China's cities, and at the same time make them more liveable for their citizens. Marco Polo described the Beijing of the 13th century as "so vast, so rich and so beautiful, that no man on earth could design anything superior to it." Indeed, China's cities of the 21st century can now build on their heritage to realise a superior future based on circular principles.

Dame Ellen MacArthur
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IN SUPPORT OF THIS REPORT

With 3,500 years of history, Wuhan is a critical city in central China. Its traditional industrial base is in steel, cars and textiles, with new development areas in electronics, energy services, and the bio-economy. Circular Economy is in line with sustainable development goals. It is a new social economy development path which can lead to both economic and social benefits and is an important way to solve resource scarcity problems. Besides being an important element of an ecological society, we should also develop the circular economy through technological innovation.

Yan Tian, Director of Resource Conservation and Environmental Protection Department, Wuhan Development and Reform Commission

Circular Economy is an important way to achieve an ecologically-civilized society. Promoting circular economy is one of the important goals in Hangzhou's 13th Five Year Plan. Hangzhou is going to comprehensively improve circular economy development in the city through further advancing pilot projects and increasing resource utilisation rates.

Qunying Lai, Director of Resource Conservation and Environmental Protection Department, Hangzhou Development and Reform Commission

C40's research, Deadline 2020: How cities will get the job done, calculated that delivering on the ambition of the Paris Agreement on climate change requires the world's megacities to act with urgency to peak emissions by 2020 and then nearly halve carbon emissions for every citizen, from an average of 5 tonnes CO2e per capita today to 3 tonnes CO2e per capita by 2030. To achieve this will require every city around the world, as well as their citizens, to reconsider how they maximise the potential of every resource and cut the amount of pollution and waste to the absolute minimum. As Chinese cities continue to grow there is a huge opportunity to create a new model of sustainable and prosperous urban development, based on circular economies. If they succeed, as this report suggests they can, it will make a huge contribution towards delivering the goals of the Paris Agreement and preventing catastrophic climate change.

Mark Watts, Executive Director, C40 Cities Climate Leadership Group

While many advancements have been made over the past few decades of rapid, double-digit GDP growth in China, it has come with some consequences. Environmental conditions, food safety, and stressed urban infrastructure, are but a few of the systemic challenges that design and circular economy thinking can address, to enable more sustainable high-value growth for China.

Charles Hayes, Executive Managing Director, Asia & Partner, IDEO

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EXECUTIVE SUMMARY

Years of double-digit GDP growth have transformed China into the world's largest manufacturer and exporter, as well as one of the most vibrant digital economies. An upper-middle-income nation, China has the largest group of middle-class citizens of any country. The recent era of rapid economic growth has increased pressure on non-renewable resources, and brought about environmental and societal challenges, such as high rates of waste generation and pollution – with consequential health hazards – and a striking disparity in access to goods and services among its citizenry. Rapid urbanisation has intensified these pressures within China's cities, which are home to 57% of the country's population (projected to reach 67% by 2030) and generate 82% of its economic output.

China's cities, then, will be the most important stages on which national efforts to harmonise economic development and environmental stewardship will play out. For more than 15 years, China's government has been a frontrunner on circular economy policies, with a focus on addressing pollution, promoting resource efficiency, and industrial ecology. Building on these efforts, in 2017 the government introduced a new set of policies, centred on concepts such as product redesign and the sharing economy, which highlight the innovation and value creation opportunities of a circular economy approach – particularly for cities. A circular economy, as defined by the Ellen MacArthur Foundation, is restorative and regenerative by design and aims to eliminate the concept of waste. These characteristics lead to new possibilities for creating economic value, along with societal and environmental benefits.

This report aims to show that realising these possibilities in China's cities will require an ambitious, systematic approach to applying circular economy principles across five high-impact areas comprised of three urban systems: the built environment, mobility, and nutrition – and two industrial systems: textiles and electronics. According to the Foundation's analysis, activating broader circular economy solutions in China's cities could significantly lower the cost of access to goods and services. Compared with China's current development path, a circular economy trajectory could save businesses and households approximately CNY 32 trillion (USD 5.1 trillion) in 2030 and CNY 70 trillion (USD 11.2 trillion) in 2040 in spending on high-quality products and services. These savings, equivalent to around 14% and 16% of China's projected GDP in 2030 and 2040 respectively, could enable more Chinese urban dwellers to enjoy a middle-class lifestyle. A circular economy approach would also reduce the environmental impacts of this lifestyle.

Development in line with circular economy principles of the five focus areas in China's cities would generate environmental and societal benefits. These take the form of higher air and water quality, increased traffic flow and safety, and improvements in public health. For example, the Foundation's analysis indicates the potential for large reductions in emissions of greenhouse gases (11% by 2030, 23% by 2040) and fine particulate matter (10% by 2030, 50% by 2040), and falls in traffic congestion (36% by 2030, 47% by 2040). Moreover, these benefits are enabled by a lower consumption of energy and materials and greater efficiency in the mobility system, which could lessen China's reliance on imported raw materials. Looking across all five areas explored in this report, the most savings are projected to come from access-based business models (as opposed to traditional product sales models), which use digital technology to increase the utilisation of assets, reduce transaction and ownership costs, and maximise value retention.

China's current development favours a circular economy, including strong investments in the shift to renewable energy, rapid development of digital technologies, and a boom in asset-sharing platforms. Nonetheless, microeconomic factors, market failures, regulatory barriers, and societal customs and habits could inhibit the realisation of a fully circular economy. Capitalising on the promise of an economy-wide transformation will require greater awareness of the size of the economic opportunity among decision-makers, as well as meaningful collaborations across government institutions, along value chains, and between public and private sectors. The recent surge in city pilots and entrepreneurial activities provides rich examples of how to implement ambitious targets. This report offers a more detailed look at these systemic shifts, and examines how they can contribute to urban and industrial innovation in China.

VISION FOR CIRCULAR CITIES IN CHINA

In the future, China's circular cities, driven by digital technology, would allow access to high-quality living space, mobility, food, and consumer goods, such as textiles and electronics, at lower cost. The decoupling of this higher standard of living from negative environmental and societal impacts would also offer residents a cleaner and healthier urban environment.

BUILT ENVIRONMENT

- Buildings would be designed to be durable, modular, and disassembled after use; be built in a resource-efficient manner; and provide more flexibility and sharing options to their users
- Citizens and business would face lower costs of accessing and running their living and working spaces, which would be more efficient, be controllable remotely, and lower their impact in terms of pollution over their lifespans
- Digitally enabled asset sharing in the built environment is already emerging: Tujia (a leading accommodation platform) provides online access to over 600,000 residential properties in China and overseas

MOBILITY

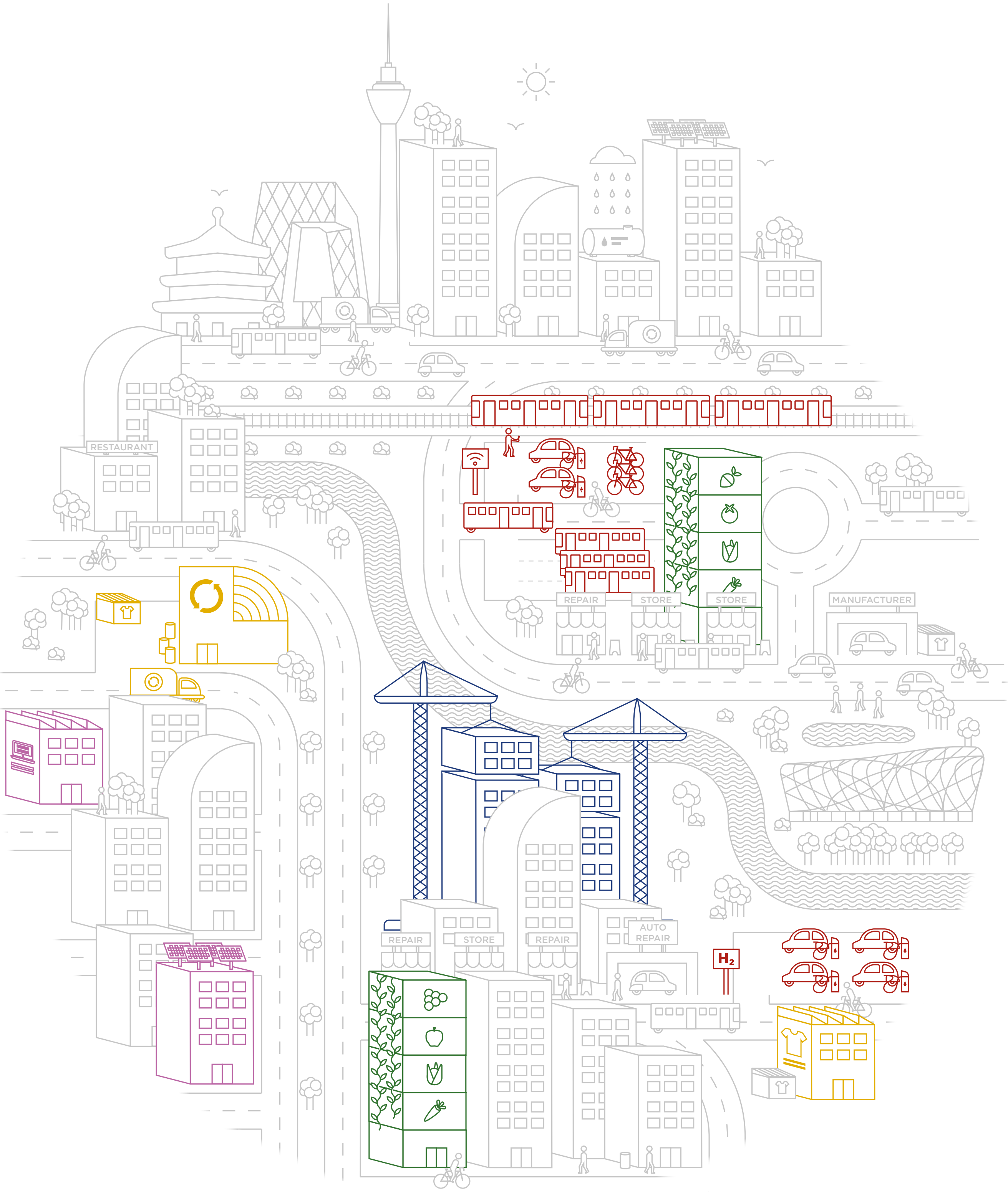
- Mobility would be provided in a shared, multi-modal, digitally enabled, integrated system, using zero emission vehicles, built using remanufactured components and recycled materials
- Citizens would be able to travel around in a more affordable and convenient way, and suffer less from traffic congestion and low air quality
- Online vehicle-sharing platforms are already popular: Didi (provider of shared cars) has 450 million users and Mobike (provider of shared bicycles) has 100 million users in China's cities

NUTRITION

- The food system in the city would use digital solutions to avoid waste and loss of nutrients along the value chain, embracing farming, for example, and return nutrients to the soil
- In such a regenerative system, China's urban dwellers would have vastly improved access to food that is reliably nutritious, healthy, and free of toxins
- Digital, on-demand farming models, such as Alibaba's JuTuDi, and online marketplaces, such as Yimutian, better predict demand and thereby tailor food production to meet it

TEXTILES & ELECTRONICS

- Consumer goods, such as textiles and electronics, would be designed, produced and used in a system that keeps products and components in use for longer, and recycles materials after use
- Urban families would access goods through a variety of models that provide utility at a lower cost – and without compromising convenience
- Zhejiang Jiaren New Materials' company plant in Shaoxing is a rare example of a chemical recycling facility that uses depolymerisation to turn waste textiles into virgin quality fibres; its annual output is projected to reach 1 million tonnes by 2021



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OPPORTUNITIES

Circular economy opportunities in China's cities have been identified in five focus areas:

BUILT ENVIRONMENT

- Design for longevity
- Industrialise construction processes
- Share space to increase asset utilisation
- Improve energy efficiency through 'green buildings'
- Enhance productivity with 'smart buildings'
- Scale up reuse and recycling of construction and demolition waste

MOBILITY

- Facilitate multi-modal shared mobility
- Scale up remanufacturing and use more recycled materials
- Design vehicles to fit a circular mobility system
- Scale up zero emission forms of propulsion
- Encourage remote and flexible working

NUTRITION

- Regenerate soil with urban food waste and wastewater
- Expand business models that promote effective agricultural supply chains
- Optimise food storage, transport and processing
- Design out loss and waste of food in the retail system
- Reinforce food consumption patterns beneficial to health and the environment

TEXTILES

- Pursue business models that increase utilisation of durable textiles
- Scale up recycling
- Introduce resource efficiency measures

ELECTRONICS

- Capture the value of e-waste through recycling
- Reuse and refurbish products, and remanufacture parts
- Encourage product-as-a-service models

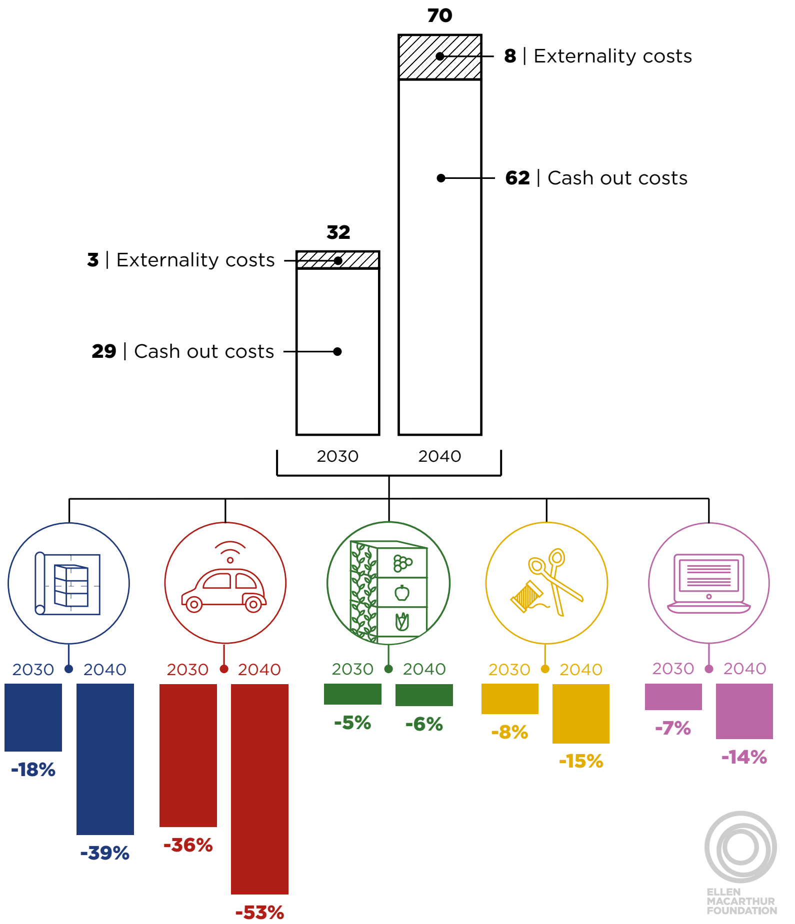
BENEFITS

Lower costs of accessing goods and services in five focus areas for circular economy opportunities in China's cities

TOTAL ECONOMIC BENEFITS IN CHINA'S CITIES*

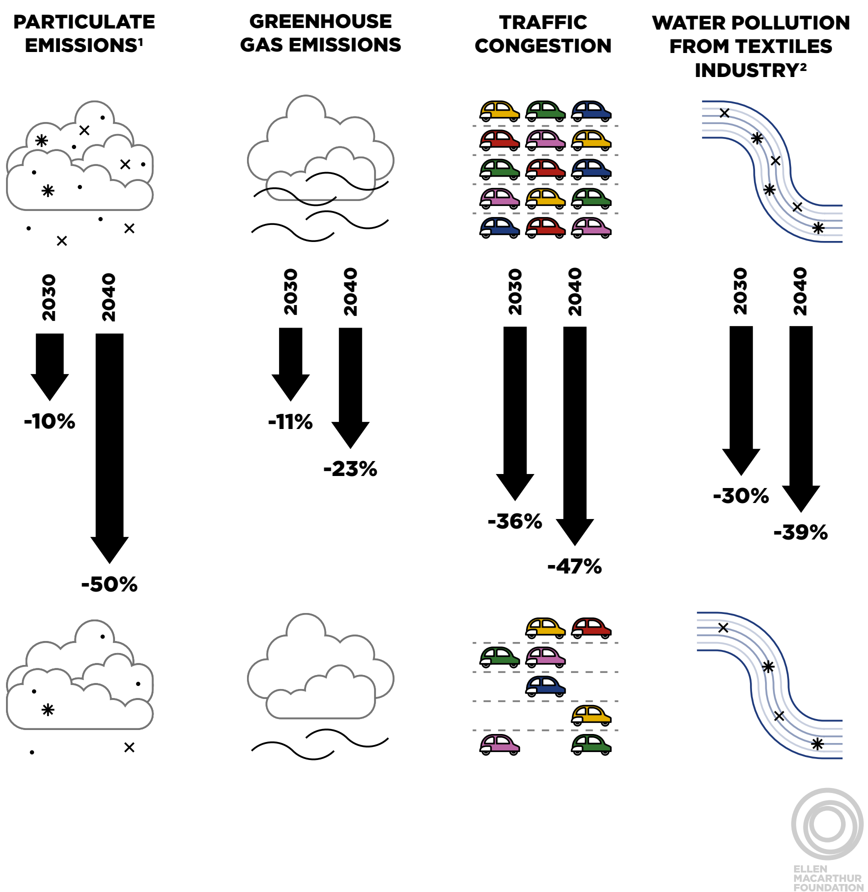
CNY trillion

COST REDUCTION BY FOCUS AREA*



Lower negative externalities for circular economy opportunities in China's cities*

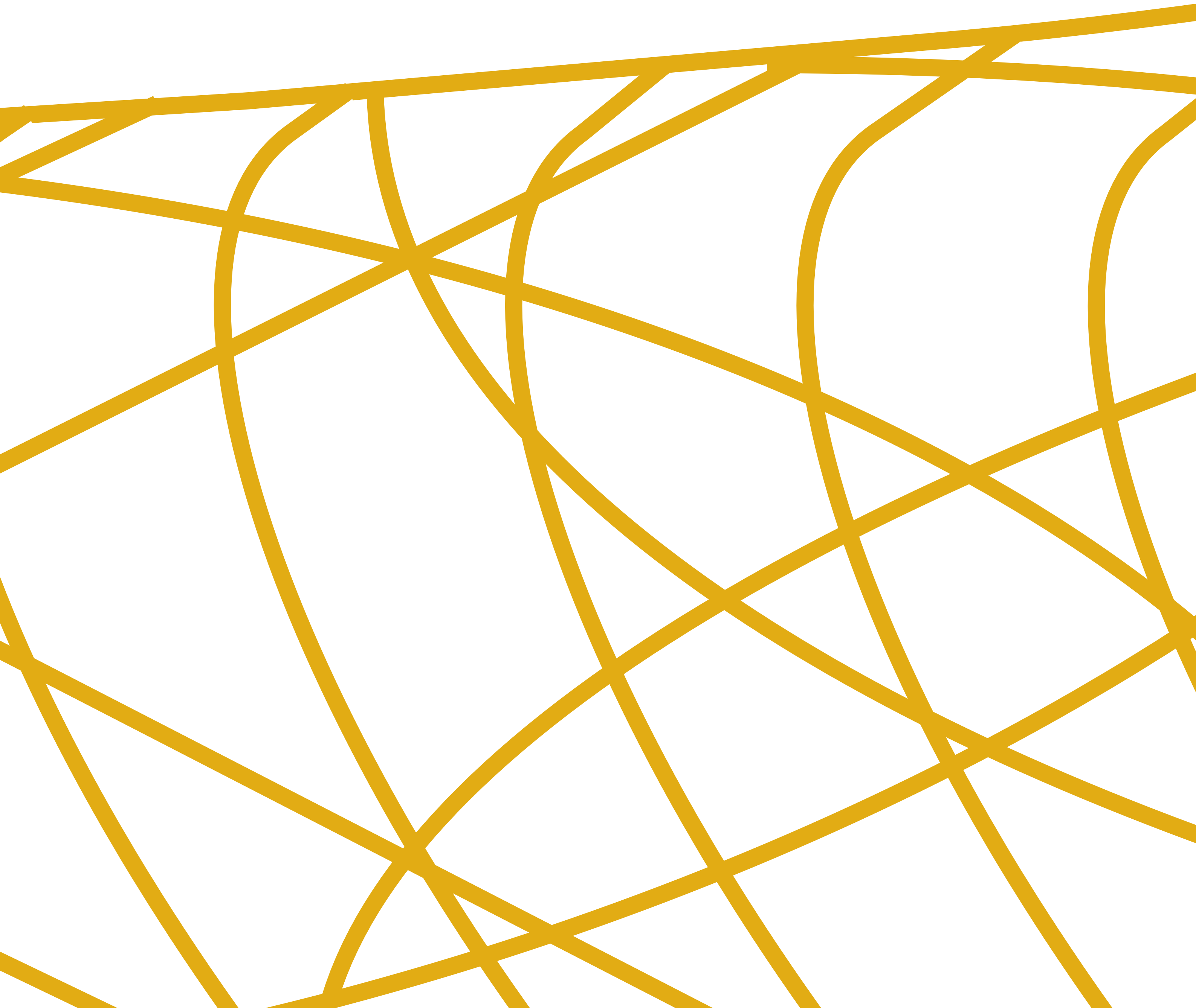
% reduction



* In circular economy scenario compared to current development pathway

1 PM 2.5

2 Expressed as a reduction in the cost of treating water pollution



SUMMARY OF FINDINGS

ABOUT THE ANALYSIS

The analysis carried out in this report highlights circular economy opportunities in the Chinese city context across three urban systems: the built environment, mobility, and nutrition – and two industry sectors: textiles and electronics. These focus areas have been selected based on their role in the national economy and their potential for circularity. Altogether, the five focus areas contribute to over 50% of China's gross value added in 2015. In addition, we have acknowledged the importance of flows of water and plastic within the urban and industrial systems in terms of their environmental and societal impact, and have examined them through the lens of circular economy principles. For each system and sector, a set of circular economy opportunities has been identified based on the Foundation team's assessment of their relevance and applicability to the Chinese urban context. This report includes extensive qualitative and quantitative analysis undertaken by the Ellen MacArthur Foundation and its partners over the past year.

Detailed quantitative analysis of the cost saving potential of circular economy opportunities was carried out by comparing costs in two scenarios, both for 2030 and 2040: the current development path and the circular economy scenario. The assumptions made for the analysis are a result of extensive desk research, as well as interviews with key stakeholders. More than 40 local and international industry experts were interviewed, from companies, universities, governmental organisations, and NGOs. Detailed methodology and assumptions are presented in the Technical Appendix.

SUMMARY OF FINDINGS

IT IS AN AUSPICIOUS TIME FOR CHINA TO ADOPT AN AMBITIOUS CIRCULAR ECONOMY AGENDA – AND ITS CITIES ARE THE PRIME PLACE TO START

After a decade of rapid GDP growth, China has now entered the 'economic new normal'. With the country's transition from being the world's factory to a major hub of innovation and advanced technology, the time has come for China to rethink its economic future as this shift throws up new challenges and opportunities. Such a period of change involves choices that are especially important when viewed against the backdrop of the Fourth Industrial Revolution[i] – in which technologies will merge into all aspects of the physical, digital and biological spheres – and the increasing drive to achieve a low carbon economy.[1]

China is at a pivotal moment in its economic development

Since the adoption of the Opening and Reform Policy in 1978, China has become the largest manufacturer and exporter in the world, gradually transitioning from a low- to an upper-middle income country, lifting hundreds of millions of people out of poverty and nurturing a booming middle class. With increased wealth, there is a shift in people's preferences towards better quality products and leisure activities. Demographic change, coupled with a surge in foreign direct investment and policy support, has driven a structural change in China's economy towards higher value manufacturing and service industries.

Economic growth has led to, and continues to be powered by, urbanisation

Rapid urbanisation is an important part of this economic reform and is considered a critical enabler in stimulating and sustaining China's development, contributing to significant GDP growth over the past three decades. Economic opportunities in cities have been the driver of rural to urban labour migration, a trend likely to continue.[2] As migrants are now also starting to move to smaller inland cities instead of only flocking to megacities, urban economic development is expected to be distributed more evenly across the country.[3] In 2016, China's urbanisation rate reached 57%[4] and cities are projected to stoke domestic demand in the economy as more urban families achieve middle-class income levels. A McKinsey study estimates that 76% of China's urban households will be considered middle class by 2022, which, as an entity, would make them equivalent to the third most populous country in the world.[5] Recognising urbanisation's role in further driving economic growth during the nation's transition to a more productive, service-based economy, China's leadership is supporting this development and is well on course to reach the goal of a 60% urbanisation rate by 2020, as outlined in the 13th Five Year Plan.

China is already taking positive steps towards a circular economy

For decades, Chinese policymakers have been exploring ways to harmonise economic development and environmental conservation.[6] In the 1990s, Chinese scholars proposed a circular economy as a new model to help China reach a more sustainable economic future. Since then, the circular economy concept has become an integral part of national economic strategy, and has been developed throughout the last three Five Year Plans.

The approval of the Circular Economy Promotion Law by the National People's

i The Fourth Industrial Revolution – a concept presented by Professor Klaus Schwab, Founder and Executive Chairman of the World Economic Forum. The Fourth Industrial Revolution is characterised by a range of new technologies that are fusing the physical, digital, and biological worlds, impacting all disciplines, economies, and industries.

Congress in 2008[7] marked China as a frontrunner in circular economy legislation. The law was primarily focused on traditional 3R (reduce, reuse, and recycle) solutions such as municipal waste management, further use of industrial by-products (industrial symbiosis), and reducing emissions from production processes.[8] The 2017 Circular Development Leading Action Plan builds on this foundation by taking important steps towards systematically tackling the root causes of environmental and societal externalities.[9] The Action Plan stresses opportunities in new digital solutions related to a circular economy. It also aims to influence the broader value chain by highlighting the potential to integrate circular economy principles at the design stage of products, and to develop new circular economy business models. Details on implementing this latest plan are still being shaped.

Existing circular economy legislation, related policies, environmental reforms, and broader economic development agendas tend to be directionally convergent. There could be, however, further opportunity to reconcile policy objectives across sectors and along value chains by enhancing policy coordination and integration. Additionally, collaboration between various governmental, corporate, and civil society stakeholders would be beneficial in realising the full potential of a circular economy.

Cities hold the most promise to realise future circular economy potential

Cities have huge potential to reduce the negative environmental impacts of China's economic development and can be a fertile ground for circular business activities. As such, they can act as prime agents to realise circular economy opportunities.

Cities are where national policies could be most effectively implemented. Regional and municipal governments could shape urban planning – including the design of mobility systems and urban infrastructure – and influence local business development, taxation, and labour markets. They could, therefore, play an active role in embedding circular economy principles across all urban functions and policies.

Cities are hotbeds for innovative circular businesses. China's cities host a broad range of talents,[10] customers, technology-savvy markets, and high concentrations of material flows, which, in combination, make them potential incubators of innovative circular solutions at scale. The sharing economy in particular has enjoyed great momentum in recent years and is predicted to account for over 10% of GDP by 2020.[11] This momentum has been largely enabled by China's recent digitalisation boom, which has made it the world's largest e-commerce market, accounting for more than 40% of global e-commerce transactions, and home to mobile payment transactions with a value 11 times those in the United States.[12]

Cities are where new infrastructure development happens. Continued rapid urbanisation presents a massive opportunity for China to apply circular economy principles from the outset, which will help bypass the linear 'take-make-dispose' lock-in currently seen in developed markets. China is planning to build almost 40 billion square metres of floor space over the next 20 years, requiring the construction of between 20,000 and 50,000 new skyscrapers – up to ten New York Cities – by 2025.[13] Implementing circular economy principles in the early stages of this development could help China leapfrog to a restorative and regenerative model that, by design, reduces the cost of accessing goods and services, and increases the utilisation of assets.

THE BENEFITS OF A SYSTEMIC CIRCULAR ECONOMY APPROACH IN CHINA'S CITIES ARE EXTENSIVE

Transforming China's economy to one characterised by circular economy principles would offer the country significant economic, environmental, and societal benefits. The following key insights on the opportunities for China's cities have been identified:

Circular economy approaches would lower the cost of accessing goods and services

Moving towards a circular economy could ensure that a higher quality of life is affordable for more Chinese urban dwellers, while, at the same time reducing the negative environmental impacts such lifestyles usually entail. Cost reductions for critical goods and services are brought about through, for example, offering new business models favouring access over ownership, replacing primary with high-quality secondary materials inputs, and leveraging digital technology to address structural waste in supply chains.

These circular economy opportunities for China's cities have the potential to yield savings of CNY 32 trillion (USD 5.1 trillion) in 2030 and CNY 70 trillion (USD 11.2 trillion) in 2040, compared with the current development path.[ii] To put this into perspective, these cost savings amount to around 14% and 16% of China's projected GDP in 2030 and 2040 respectively. These savings are expressed as a reduction in the total cost of access (TCA), a concept closely aligned with the total cost of ownership but applied to cases where the user does not necessarily own the relevant goods or assets. TCA comprises the cash-out costs of accessing the goods and services, and the costs of the negative environmental and societal impacts associated with their production, use and after-use pathways. A lower TCA indicates that the costs of accessing a certain level of goods and services would be significantly lower in the circular economy scenario.[iii]

The cost reductions are mostly driven by savings in the built environment and mobility since their circular economy opportunities play out right across a city. In comparison, supply chains for the two industry sectors examined – textiles and electronics – are often concentrated in clusters outside city borders. Therefore, only part of the value chain has been taken into account for these sectors, for example, leaving out the production stage in the electronics sector, the sourcing of primary materials in the textiles sector, and rural agriculture in the nutrition system.[iv]

INVESTING IN CIRCULAR ECONOMY OPPORTUNITIES

How might investment requirements affect decisions to pursue circular economy opportunities? There is a first set of opportunities that comes with little or no investment requirement and because of this the net benefits outlined in the report reflect well the cost of execution. These opportunities include efforts to modify customer behaviour. There are those with moderate and quite clearly defined investment requirements. Many of the efforts to build better end-of-life pathways for products and materials fall into this category. Finally, investment-heavy interventions can mainly be found in the sectors that yield the largest benefits in this report's analysis, namely mobility and built environment. Any investment decision here would require a more granular perspective on the opportunity before moving ahead with the – inherently complex – assessment process. The analysis does not include the incremental capital expenditure needed to put them in place. This was a deliberate choice, made to avoid obscuring the relative benefits of opportunities within a sector and across sectors.

ii For 2030, this includes CNY 29 trillion (USD 4.7 trillion) in user cash-out benefits and CNY 3 trillion (USD 0.5 trillion) in externality benefits for cities; for 2040, CNY 62 trillion (USD 10 trillion) in user cash-out benefits and CNY 8 trillion (USD 1.3 trillion) in externality benefits.

iii Total cost of access (TCA) is made up of cash-out costs and externality costs. Cash-out costs exclude government subsidies and incremental capital expenditure (the added investment needed to move to the circular economy scenario). Externality costs represent the economic costs, such as lost earnings and healthcare expenditure, associated with, for example, emissions of greenhouse gases and particulates. Details can be found in the Technical Appendix.

iv Another reason for the relatively modest circular economy benefits for nutrition as estimated by this report is that some of the behavioural changes, such as changing the diet, were not reflected in the modelling.

A circular economy would provide environmental, societal, and resource benefits

A circular economy development path would reduce negative impacts on the quality of life in cities by the following amounts:

- Emissions across all sectors of fine particulate matter (PM2.5),[v] which damages public health, by 10% in 2030 and 50% in 2040
- Emissions of PM10[vi] particulate matter, which also has negative impacts on public health, from the built environment sector by 18% in 2030 and 72% in 2040
- Emissions from the transport system of nitrogen oxide pollutants (NO_x), which damage public health and contribute to acid rain, by 9% in 2030 and 19% in 2040
- Traffic congestion and its associated time and economic costs by 36% in 2030 and 47% in 2040
- Traffic accidents and fatalities, including the associated costs of medical treatment,[vii] by 20% in 2030 and 28% in 2040
- Costs of treating water pollution from the textiles industry, which has negative impacts on health and aquatic environments, by 30% in 2030 and 39% in 2040

This development path would also lead to reductions in greenhouse gas emissions by 11% in 2030 and 23% in 2040 compared to the current development path. This means it could act as one of China's delivery mechanisms for its commitments under the Paris Agreement and any future commitments to reducing greenhouse gas emissions. The mix of environmental and societal benefits shows that the circular economy agenda can contribute towards China meeting the UN Sustainable Development Goals (SDGs). An ambitious and broad agenda could further establish the country's leadership position on the subject at international forums such as the G20, WTO, and UN, potentially becoming a beacon for others to follow.

Furthermore, implementing circular economy opportunities would result in a decrease in consumption of non-renewable resources, including fossil fuels, of between 3% and 49% by 2030, and 8% to 71% by 2040, depending on the focus area. Taken together they would significantly reduce China's reliance on importing raw materials.

Large-scale urban innovation opportunities would offer new areas of competitive advantage

With China's transition from the 'world's factory' to an innovation powerhouse, its rising middle class will increasingly build their prosperity on the service industry and high-value manufacturing. China's cities already host a broad range of talents and have the potential to become hotbeds for innovative business solutions. The geographical proximity of producers and users in urban centres makes reverse logistics, material collection infrastructure, and sharing business models more efficient. In addition, the volume and concentration of materials offers economies of scale. Accelerating progress towards a circular economy vision presents China's cities with substantial opportunities to act as global frontrunners in certain sub-sectors, mirroring successes in, for example, electric vehicles. On a more macro scale, they could also be seen globally as sources of inspiration in urban development, due to their experience of meeting challenges in a 'circular' way and at a rapid pace.

Leveraging digital platforms is key to the circular economy opportunities and would give Chinese city dwellers access to a wider range of assets

While all the opportunities identified in this report result in cost savings in the circular economy scenario compared to the current development path, the highest impact at a city level is generated by opportunities that favour access over ownership. Total savings across shared multi-modal mobility, shared living and working space, and access over ownership models for textiles, amount to

v Particulate matter, with a diameter of 2.5 micrometres (μm) or less, typically emitted during the combustion of solid and liquid fuels, such as for power generation, domestic heating and in vehicle engines.

vi Particle matter with a diameter of 10 micrometres (μm) or less.

vii The cost was kept constant across 2030 and 2040.

CNY 16 trillion (USD 2.6 trillion) in 2030 and CNY 38 trillion (USD 6.1 trillion) in 2040. The sharing economy, enabled by digital platforms, allows users to increase access to underutilised assets, thus generating value and catering to an increasing need for flexibility in private and work life. It also helps overcome the high administrative and financial hurdles of ownership, for example in the form of the lottery for private vehicle licence plates in some cities, car ownership tax, and travel restrictions dependent on licence plate numbers.

In mobility, facilitating multi-modal shared mobility contributes 89% of the savings in 2030 and 80% in 2040. Here, the operational costs per vehicle-km are reduced by the improved utilisation of vehicles, through convenient public transport options and sharing platforms, and by introducing more electric and material-efficient vehicles into the fleet. Sharing services offer convenient access to various types of vehicles and, together with new technologies such as autonomous vehicles, different modes of transport can be combined whenever required.

Multi-modal shared mobility is also one of the key drivers in reducing greenhouse gas emissions. By implementing this opportunity China's cities could reduce the total CO_2 emissions related to mobility by 22% in 2030 and 37% in 2040. Mobility services and vehicle-sharing platforms could also help reduce congestion by shifting the vehicle mix towards an increasingly multi-modal transportation system, in which more passenger-kilometres are provided by public transport.

HOW TO REALISE THESE OPPORTUNITIES IN CITIES

A city's development stage and industry focus will determine its circular economy priorities

While circular economy opportunities exist for all types of cities, decision-makers at the municipal level could prioritise them according to their city's characteristics. This report has developed a framework to categorise cities into archetypes based on certain shared characteristics relevant for circular economy development. Our analysis has shown that the development stage of a city (defined by size and growth rate of GDP and population) and its industry focus are both relevant to this prioritisation.

For example, a developed megacity has the advantage of having a larger share of middle-class consumers whose demand for high-quality food could support organic urban and peri-urban[viii] farming; whose exposure to digital technologies could allow digitally enabled sharing and pay-per-use schemes; and who are likely to provide sufficient stocks of secondary textiles and electronic products to enable up scaling of collection and closed-loop activities. On the other hand, a city under development and expansion has a great opportunity to leapfrog into urban design based on circular economy principles. For example, the mobility system could be designed to be suitable for zero-emission, shared, and multi-modal mobility from the very beginning of construction, for example incorporating Transit-Oriented Design, cycling paths, and electric vehicle charging stations.

When it comes to industrial focus, a city with a well-developed service industry could aim to decouple its growth from negative environmental impacts by stimulating key technologies that enable circular economy opportunities. Examples include Big Data solutions that feed into shared mobility schemes or the digital technology needed to track and trace materials. On the other hand, a city generating most of its economic value from manufacturing industries could stimulate more effective use and reuse of

viii Peri-urban – a transition area between urban and rural zones.

the products it makes, and the materials it uses to make them, thereby upgrading and de-risking its industrial base.

Policymakers can draw on examples to help overcome implementation barriers and unlock opportunities

Implementing circular economy opportunities in cities could be hindered by a variety of barriers. In this report, we consider four main categories: economic barriers; market failures; regulatory failures; and societal factors, based on a framework developed as part of the *Delivering the circular economy – a toolkit for policymakers* report.[14] The same report lists the six major intervention types at the disposal of policymakers at national, regional, and city level to overcome these barriers: regulatory frameworks; fiscal frameworks; public procurement and infrastructure investment; business support schemes; collaboration platforms; and education, and information and awareness building.

The significance of the barriers varies across the three urban systems and two industry sectors covered by this report. Based on interviews with industry players across the five areas, and further research, an initial prioritisation analysis has been carried out that identifies the main barriers and notes some current policy responses in China to overcome them along with examples of similar interventions in other countries. The main barriers found were:

Lack of access to capital and uncertain payback times. These are a key hindrance not only to the construction of 3D printed buildings, but also to industry schemes to close loops in organic materials, textiles, and electronics. China has many existing initiatives to mitigate this issue. For example, the Chinese government has been actively promoting public-private partnership (PPP) schemes by establishing information platforms and regulations.[15] One such example is the China PPP Service platform,[16] which provides a project database, policy information, and successful case studies to attract investors. Another measure is public procurement, such as that implemented by the Beijing municipality to support the prefabrication of buildings.[17] Further economic incentives, such as tax refunds and subsidies, have also been tested, for example by the government of Shandong, also to support prefabrication in construction.[18] When it comes to investing in energy efficiency, an important mechanism to unlock capital for energy-efficiency measures is the Energy Service Companies (ESCO) or Energy Management Companies (EMCo) in China. These companies provide a 'full service' model – identifying, designing, financing, and overseeing installation of energy-efficiency projects, receiving a share of the resulting energy savings. It has been suggested that as the EMCo industry grows in China, and as banking sector reform continues, EMCos will increasingly be able to obtain financing directly from local banks.[19]

Unpriced negative externalities. These could be a barrier to circular economy opportunities in any sector and anywhere along a value chain. When the price of materials does not include the true cost of their negative impacts, and when landfill prices do not account for their methane emissions or toxins leaching into the surrounding land or water, the incentive to keep materials in circulation is not sufficiently strong. Internationally, carbon pricing has been an instrument used to help level the playing field.[20] At the city level, the fast-growing number of low-emission zones and other access regulations introduced by city planners around the world aims to do a similar thing: reduce externalities by factoring them into the cost of combustion engine-based mobility.[21]

Inadequately defined legal frameworks. While these can take many forms, a prominent example is the definition of 'waste', which can limit the reuse and recycling of by-products, for example in the food and construction industries. This barrier could be addressed with clearer definitions, instructions and standards on the processing of by-products, as well as on the quality of the input and output. China's year-long National Sword campaign, initiated at the beginning of 2017, is an example of such a policy.[22] While its efforts to improve the quality of imported feedstock have been closely followed by the international community, the campaign also seeks to root out illegal processors and substandard recycling facilities in China. In Europe, the EU aims to facilitate the return of 'waste' materials into the economy through the introduction of so-called 'end-of-waste' criteria. Such standards might be developed by industry too. Take the example of compost, where contaminants like heavy metals might severely limit its possible applications and, therefore, its market value. In the UK, a Publicly Available Specification for composted materials was developed by the charity WRAP, together with the Organics Recycling Group.[23]

Custom and habit. People's views on product and asset ownership, and their lack of trust of pre-owned products takes time to change. Private sector digital-sharing platforms have identified new mechanisms to create the necessary trust. For example, Tujia, a Chinese peer-to-peer accommodation rental service, provides a review opportunity on both the supply and the demand side. While Tujia's review process is still facing early stage business challenges, platforms with a longer history, such as eBay and Airbnb, have demonstrated that the process can be lifted to a level where trust is no longer a barrier to participation. Governments could influence retailers, service crews, and others with customer contact to guide and reinforce behaviour. Indeed, the French government issued a decree making it compulsory for automotive repair shops to inform customers that they have the choice to use remanufactured parts, putting forward arguments including waste reduction, reduced resource use, and reduced prices for the end-user.[24]

The transition to a circular economy requires action from and collaboration between public and private stakeholders

In a transition to a circular economy, action is needed from stakeholders across the economy. It is vital that current and future designers, engineers, strategists, and marketers are equipped with the capabilities and skills to develop successful circular economy solutions – to think in systems. One of academia's key roles is to address research gaps and inform and inspire the next generation of learners. Companies can create the required buy-in so that customers actively demand higher product quality and safety, and increasingly accept and appreciate access over ownership models.

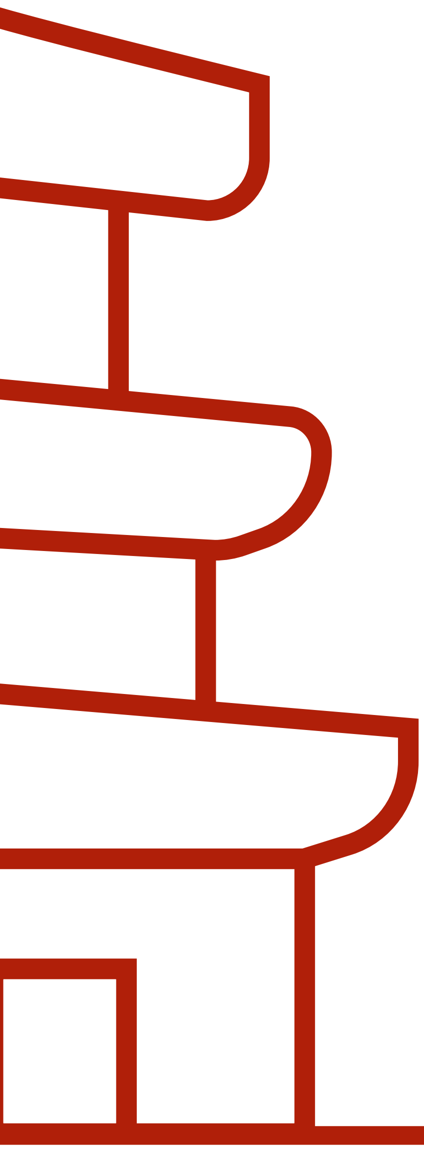
Importantly, a multi-stakeholder collaboration with actors from various spheres and sectors could be the most effective tool in facilitating the successful transition to a circular economy. Such interactions are essential to overcome silos and could be in three main forms:

- **Across government institutions:** for example, the Shanghai municipality, with support from various stakeholders such as the Ministry of Environmental Protection, the Development and Reform Commission and the Municipality Financial Department, charges fees to electrical appliance producers, puts the proceeds in a fund, and uses it to give subsidies to e-waste processing companies.
- **Along the value chain:** for example, the New Plastics Economy initiative,[25] led by the Ellen MacArthur Foundation, brings together global consumer goods companies, retailers, plastic producers, plastic packaging manufacturers, cities, and businesses involved in collection, sorting, and reprocessing, with the aim to move the plastics value chain into a positive spiral of value capture, stronger economics, and better environmental outcomes.
- **Between government and business:** for example, Shanghai city is supporting the company Yuanyuan to develop chemical recycling by registering them as the designated textile recycling company as part of the city's circular economy and cleaner production project, and granting them a VAT reduction.

Overall, a systemic shift to a circular economy could benefit from a close integration of national and regional policy programmes across sectors, coordinated by a unified circular economy framework as well as a full range of public and private collaborations. Local, national, and international lighthouse projects and best practices could help to make ambitious targets tangible and actionable. The circular economy is a framework for innovation and value creation for businesses, large and small, private and state-owned.

Due to their sheer innovative power, China's cities have the opportunity to take centre stage in this transition and become beacons of a successful circular economy approach both at home and abroad.

1. AN AUSPICIOUS TIME FOR AN AMBITIOUS CIRCULAR ECONOMY AGENDA



AN AUSPICIOUS TIME FOR AN AMBITIOUS CIRCULAR ECONOMY AGENDA

After decades of rapid GDP growth,[26] China has now entered the 'economic new normal'.[i] With the country's transition from being the world's factory to a major hub of innovation and advanced technology, the time has come for China to rethink its economic future. Such a period of change throws up new challenges and opportunities, particularly when viewed against the backdrop of the Fourth Industrial Revolution[27] – in which technologies will merge into all aspects of the physical, digital, and biological spheres – and the increasing drive towards a low-carbon economy.

CHINA IS AT A PIVOTAL MOMENT IN ITS ECONOMIC DEVELOPMENT

Since the adoption of the Opening and Reform Policy in 1978, China has become the largest manufacturer and exporter in the world, gradually transitioning from a low- to an upper-middle income country, lifting hundreds of millions of people out of poverty.[28] In addition, since 2015, China has had the largest middle-class group by population in the world[29] with average per capita urban disposable income rising from CNY 3,912 (USD 628) to CNY 31,195 (USD 5,007) between 1995 and 2015.[30]

These shifts in income have led to changes in consumer behaviour. As consumers achieve middle-class income levels, they find themselves able to spend more money on cars, durable goods, higher-quality products, luxury items, and leisure activities. By 2022, China's middle class will make up to 76% of its urban households and drive domestic consumption.[31] In real terms, average urban consumption expenditure per capita more than quadrupled from CNY 3,538 (USD 568) to CNY 16,691 (USD 2,679) from 1995 to 2014.[32]

These socioeconomic changes, coupled with a surge in foreign direct investment and policy support from central and local governments, has catalysed a structural shift in China's economy. The contribution made to GDP by the three main industry sectors (primary, secondary, and tertiary)[ii] changed from 19.6%/ 46.8%/33.7% in 1995 to 8.8%/ 40.9%/50.2% in 2015.[33] Since 2015, secondary and tertiary sectors have remained the key drivers of China's annual GDP growth. Despite the gradual drop in the primary or material production sector's contribution, industrial activities continue to be accountable for the largest share of GDP at 34.3% in 2015. The other two most important industry sectors in China are wholesale and retail trade accounting for 9.7% GDP and financial intermediation at 8.4%.[34] In recent years, the sharing economy has gathered great momentum in China, powered by rapid innovation, price-conscious consumers, and Chinese citizens being quick to adopt new technologies and business models. For example, China is the world's largest e-commerce market accounting for more than 40% of the value of worldwide e-commerce transactions, and mobile payments in China are 11 times the transaction value of the US.[35] With new sharing schemes quickly emerging and gaining market share, the sharing economy sector is predicted to account for over 10% of China's GDP by 2020.[36]

Economic growth has led to, and continues to be powered by, urbanisation

Rapid urbanisation has transformed China's economy. By April 2017, China's urbanisation rate reached 56.1%[37] and is expected to

i This GDP growth has dipped to 7% post-financial crisis.

ii Primary industries refer to those dealing with products taken directly from nature, i.e.. agricultural. Secondary industries refer to those processing primary materials, i.e.. manufacture. Tertiary industries refer to the rest, i.e.. logistics, tourism, finance, education etc.

increase to nearly 70% by 2030.[38] Overall, this shift has contributed to more than 20% of GDP growth during the past three decades.[39] Urbanisation, though not always a driver of growth, is considered a critical enabler in stimulating and sustaining China's development[40] because cities are where economic opportunities emerge and wealth accumulates. A McKinsey study estimates that 7% of China's urban population will be considered middle class by 2020, which, as a group would make them equivalent to the third most populous country in the world.[41] This expansion is expected to further unleash the potential of domestic demand. Indeed, by the end of 2016, 12 of China's cities had reached a GDP above CNY 1 trillion (USD 0.16 trillion).[42] In the same year, the top 100 cities in China generated 75.7% of the total GDP, with the vast majority[iii] having above national average growth rates.[43] Looking forward, China's emerging city consumer market[iv] will further drive urban economic development due to rising wages and increased disposable income.[44]

Economic opportunities in China's cities have been the driver of rural to urban labour migration during the past decades and this trend is expected to continue in the future, albeit with a slight shift of focus.[45] It is predicted that the speed of migration will be sustained but instead of flocking to Tier[v] 1 and 2 cities,[46,vi] domestic migrants are now also moving to smaller inland cities.[47] The level of urbanisation in China so far has been impressive. However, it is still below the 70% level typical for countries at China's current per capita income levels.[48] Recognising urbanisation's role in further driving economic development during the nation's transition to a more productive, service-based economy, China's leadership is continuing to promote and encourage this development and is well on course to reach its goal of a 60% urbanisation rate by 2020, as outlined within the 13th Five Year Plan.

CHINA'S POSITIVE INITIAL STEPS TOWARDS A CIRCULAR ECONOMY CAN NOW BE ACCELERATED

China's aim of promoting the circular economy is to 'harmonise' economic development and environmental conservation through achieving the most economic and societal benefits, while minimising resource consumption and adverse environmental consequences.[49] Inspired by examples of industrial ecology in Europe and Japan, Chinese scholars first proposed the circular economy as a new development model in the 1990s, to help China develop a more sustainable economic development path.[50] Since then, the concept of the circular economy has gradually become a key part of the national strategy for economic development. Early initiatives had a focus on 'reduce-reuse-recycle' principles to address environmental issues (e.g. improving municipal waste management, further utilising industrial by-products through industrial symbiosis, and reducing emissions from production processes). In contrast, more recent circular economy policies are focused on systematically tackling the root causes of environmental and societal externalities by looking at design-led measures and intensifying asset utilisation through new business models.

On the political agenda, the concept of the circular economy was first introduced in 2002 at the Second Global Facility Assembly, where it was stated that "only by following the path of circular economy, based on an effective use of resources and environmental protection, will it be possible to achieve sustainable development".[51] Acknowledging the conflict between economic development, environmental degradation, and societal concerns, alongside the need to build a 'xiaokang shehui' (the Chinese term for a 'well-off society'), the government endorsed the concepts of harmonious development

iii Of the 100 cities, 88 had a GDP growth rate above the national average (6.7%) and six of them had a growth rate of more than 10%.

iv The average per capita urban disposable income rose by about 600% between 1995 and 2014. By 2022, 76% of Chinese families will reach middle-class levels and will have doubled their income since 2010.

v The commonly used Chinese tier system which was originally based on the Chinese government's classification system, but now there are different methods considering GDP, population, retail sales, etc.

vi During the period from 2000 to 2010, the biggest cities used to increase by 10 million migrant workers per year.

and ecological civilisation.[52] The latter idea has now become the cornerstone of the Chinese Communist Party's long-term vision of sustainable development, which aims to address the systemic obstacles to environmental governance.[53] With recent policies, the circular economy was recognised as an important pathway to establishing an ecological civilisation.

In terms of practical implementation, China's State Environmental Protection Administration (SEPA – later transformed into the Ministry of Environmental Protection), with the support of the World Bank, launched demonstration projects focusing on cleaner production in 1993 and began to pilot eco-industrial parks (EIPs) to advance the circular economy development a decade later.[54] At the time of writing, the total number of circular economy pilots and demonstration projects had exceeded 2,300 (with some sources estimating that there have been as many as 6,200 projects over the past ten years).[55] Alongside these pilots, various special policies on pollution prevention and control (e.g. Solid Wastes and Water Pollution) and on natural resources (e.g. Mineral Resources, Water, and Soil), alongside those targeting specific sectors, were launched. This legislation has formed the basis for developing the legal framework that underpins the circular economy in China.[56]

Policies aimed at accelerating the transition to the circular economy in China can be seen within the Five Year Plans starting from 2006, along with the establishment of a system of comprehensive indicators to enable the government to track implementation progress (see Box 1):

- The 11th Five Year Plan (2006–10) was the first to place strategic importance on the development of the circular economy. This plan suggested the practical implementation of the circular economy at three levels (enterprises – micro; industrial parks – meso; and cities and regions – macro). It resulted in the publication of the Circular Economy Promotion Law in 2008, one of the first pieces of circular economy legislation in the world, with a focus on the 'Reduce, Reuse, Recycle' (3R) principle
- During the 12th Five Year Plan (2011–15), China's National Development and Reform Commission (NDRC) synthesised 60 best practices from the pilot projects at enterprise, industrial park, and regional levels.[57] It also upgraded the circular economy to a national development strategy by scaling up the demonstration of the circular economy within the Development Strategy and by launching the Immediate Action Plan of Circular Economy in 2013. This action plan outlined how the demonstration pilot programme would target ten projects, 100 cities and 1,000 enterprises
- The current 13th Five Year Plan (2016–20) keeps the circular economy and low-carbon economy as key focus areas for policy. It introduces binding targets relevant for the circular economy, emphasises the importance of an Extended Producer Responsibility (EPR) framework, and proposes to further strengthen municipal waste management and the remanufacturing industry

The release of several relevant new policies in 2017 marked another milestone in China's progress on circular development policy frameworks. First, the EPR plan stipulated the role producers must play in resource conservation and environmental protection throughout the lifecycle of their products, from design to waste management. Electronics, automobiles, lead acid batteries, and packaging products were selected as the priority areas for implementation of the plan. The Circular Development Leading Action Plan, released in May 2017, takes important steps towards systematically tackling the root causes of environmental and societal externalities[58] by stressing opportunities in new digital solutions related to the circular economy. It also aims to influence the broader value chain by highlighting the potential to integrate circular economy principles at the design stage of products, and opportunities to develop new circular economy business models. Moreover, to address the booming sharing economy, the first regulation and guideline on its promotion was released in July 2017. This acknowledged not only the impact sharing models have had on China's economy, but also their potential for improving resource efficiency through their service over ownership principles, and by providing employment. The policy proposed collaborative governance of the government, business, associations, and consumers in the sector to establish a fair and safe environment for the sharing economy's further development.[59] Last but not least, the government announced their intention to ban 24 categories of foreign solid waste imports, such as plastics and unsorted waste paper, by the end of 2017,[60] and the policy has come into force in January 2018.[61]

As we have seen, recent policy changes have heralded a shift from China's previous focus on a clean-up approach to a more holistic view of tackling the inherent negative environmental and societal externalities of the current linear focus.

BOX 1: THE CIRCULAR ECONOMY DEVELOPMENT EVALUATION INDICATOR SYSTEM

In order to assess implementation of the circular economy in practice, the NDRC, together with the Ministry of Environmental Protection (MEP) and the National Bureau of Statistics (NBS), developed the first circular economy index system in 2007,[62] and released an updated version in January 2017. These indicators are based on the Material Flow Analysis (MFA) method[63] and have been designed to assess circularity on macro and meso levels in line with the 3R principles.[64] The new system has a more complex structure made up of three main interconnected categories:

- **Comprehensive indicators:** measure the overall productivity of main resources, such as fossil fuels, metals, minerals, and biological resources. They also measure the recycling rate of the main waste streams from agriculture, industries, urban construction, and urban food etc.
- **Specialised indicators:** measure specific streams of resource productivity, waste recycling rates, and the value added by recycling industries
- **Supplemental indicators:** focus on the end-of-pipe treatment of waste, such as industrial, solid, and wastewater municipal waste, and the emission of main pollutants

These indicator categories then jointly form one composite indicator – the circular economy development indicator – which measures and tracks China's overall progress towards a circular economy.[65] The latter indicator reached a level of 137.6 in 2013, compared to the baseline of 100 in 2005. Most notable improvement includes:

- Major pollutants treatment rate index increased by 74%
- Waste emission intensity index improved by 46.5%
- Resource consumption intensity index improved by 34.7%
- Waste utilisation index increased by 8%[66]

During the 12th Five Year Plan, the municipal waste treatment rate reached 94% and the urban wastewater treatment rate reached 92%. National levels of chemical oxygen demand (COD), SO_2, and NOx emissions decreased by 13%, 18%, and 19% respectively.[67] Air quality also improved in 2016 compared to 2015, with the number of good air quality days increasing by 2.1%, the number of heavy pollution days decreasing by 0.6%, and the PM2.5 and PM10 concentration levels decreasing by around 6% each. The 13th Five Year Plan aims to speed up the process of building treatment and utilisation systems for municipal food and kitchen, construction and textiles wastes.[68]

This vision translates into specific action points that will address the drawbacks of certain material flows. For example, policymakers banned plastic bags in 2008,[69] which resulted in a 66% drop in plastic bag use (saving approximately 40 billion bags) after a year of effective implementation.[70] Operation Green Fence, implemented by the Chinese government since 2013, aimed to control the quality of imported recyclables and to restrict the amount of contaminated secondary material being exported to China.[71] This operation saw 70% of imported recyclable waste containers being controlled in the first year and 800,000 tonnes of recyclables or scraps being rejected because of their quality in the first six months.[72] The launch of the Chinese National Sword campaign in 2017 aimed to further crack down on deliberate smuggling of improper solid waste imports and processing,[vii,73] and to ban the import of

vii Mainly focusing on industrial waste, e-waste, plastics, and other solid waste.

certain waste materials,[viii] including plastics.[74,75]

The central government has also targeted the prevention and control of water pollution, with numerous pieces of legislation and policies being introduced and refined over recent years.[76] In 2014, the water performance of 17 eco-industrial parks was assessed over a period of two to four years. Although freshwater consumption increased in absolute terms, all parks showed relative decoupling of consumption against economic output, so increasing water productivity. Design philosophies such as 'sponge city'[ix] have also been implemented in Shenzhen, allowing for better infiltration, storage and treatment of rainfall, replenishing aquifers, and reducing the risks of flooding.[77]

China has also stepped up its support of renewable energies, gaining global recognition and making strides towards achieving the COP21 goals established at the 2015 Paris Climate Conference in the process. China has now become an irreplaceable stabiliser in global renewable energy investment, channelling more than USD 100 billion annually into the sector in recent years.[78] In 2015, China invested USD 103 billion in renewables, amounting to one-third of the world's total input and double that of the US. Domestically, the share of non-fossil fuel energy has also been increasing steadily, from 8.6% in 2010[79] to 13.2 % in 2016.[80] The State Council has formally set the goal of having 15% of primary energy consumption coming from non-fossil sources by 2020.[81] By 2030 China's CO_2 emissions are expected to peak and its energy intensity (the amount of energy consumed per unit of GDP) could be reduced by 60–65% compared to 2015.[82] In December 2016 China released their first climate change update report, which indicated that the country has made more than 40% progress towards its 2030 goals.[83]

Additionally, China has been investing heavily in high-tech manufacturing and service industries, the funding for which increased 19.5% between 2003 and 2013. The country's investment in science and engineering R&D has also been significant,[x] amounting to 20% of the global total in 2016.[84] China Manufacturing 2025, a policy issued in 2016, is another declaration of the country's commitment to technological innovation in ten manufacture industry areas, including IT, Renewable Energy Vehicles, new materials, etc. This policy works alongside China's plans to boost trade and stimulate economic growth across Asia, and beyond through the One Belt, One Road initiative.[xi,85,86] This initiative opens up the opportunity to export the country's experiences of implementing circular economy principles to key trading partners and future value chain participants, especially in the construction and industrial sectors throughout southeast and central Asia to the Middle East, Europe, and Africa.

It is clear that such existing policies aimed at accelerating the transition to the circular economy, along with the economic development agendas and the broader environmental reforms, jointly constitute the essential building blocks towards a modernised strategy for long-term economic development for China. However, while these blocks tend to be directionally convergent, they are also fragmented. In order to reconcile the objectives across different sectors in the economy in general, and along specific value chains in particular, policies need to be mutually reinforcing and integrated within a more holistic framework. To achieve harmonious development and further accelerate and deepen the transition to a circular economy, the implementation of a coordination mechanism across policies, the involvement of various governmental, corporate, and civil society stakeholders, as well as coordination and active collaboration among them will be essential.

Nevertheless, these new innovations in business models and technology, the introduction of supportive policy frameworks and increasing customer openness to such changes, mean that the time is ripe for China to embrace these opportunities and accelerate the circular transition now.

viii Including e-waste, household waste, agricultural films and tubes, bottles, etc. Irregular processing, such as by small factories which do not proceed with proper pollution controls. Campaign also aims to actively take the initiative to cooperate with environmental protection departments.

ix The idea of 'sponge city' aims at storing rainwater, especially during heavy rainfall, to prevent floods and release it for the benefit of residents during dry times.

x This places China immediately after the US in investment terms in these areas.

xi An initiative to connect China by land and sea to southeast and central Asia, as well as beyond to the Middle East, Europe, and Africa.

CITIES ARE THE PRIME PLACES TO REALISE THIS POTENTIAL[xii]

As urbanisation continues, increasingly many people are impacted by the resulting environmental and societal issues in China's cities. Fortunately, opportunities often lie where the challenges are. As rapid urbanisation persists, cities that are already powerhouses of economic activity, have huge potential to increase system effectiveness since their complex networks of interlocked infrastructure host highly concentrated flows of biological and technical nutrients.[87] As such, cities are key to China unlocking the further potential of the circular economy. Indeed, in a circular scenario, China's cities, individually or as clusters, could become hosts of national and international innovation and operational excellence in globally competitive technologies that enable circular economy practices.

National policies can be most effectively implemented at city scale

The provincial and municipal governments in China directly influence urban planning, the design of mobility systems, urban infrastructure, local business development, taxation, and the local job market. They can, therefore, play an active role in embedding the principles of the circular economy across all urban functions and policies. Many of China's cities have already set up circular economy demonstration projects tailored to their industrial and urban characteristics (e.g. Shanghai's e-waste recycling industries and Guangzhou's organic waste collection and treatment project, see Case Study 5).

Cities can become hotbeds of innovative circular businesses

China's cities, already home to a broad range of highly innovative individuals and organisations,[88] and technology savvy markets, could become hotbeds of innovative circular business solutions. Reverse logistics, material collection cycles, and sharing business models could be more efficient and effective due to the geographical proximity of users, producers, and service providers. This would create more opportunities for reuse and collection-based business models. In addition, the volume and concentration of materials in cities could offer economies of scale, which could be further advanced by digitisation as the Fourth Industrial Revolution unfolds.

Cities are where new infrastructure development happens

Continued rapid urbanisation presents a massive opportunity for China to apply circular economy principles from the outset, which will help to avoid the linear 'take-make-dispose' lock-in currently seen in developed markets. Additionally, if planned ahead and managed appropriately, the stranded asset risk,[xiii] which is increasingly demonstrated to be associated with the linear economy, could be avoided in China's cities. China is planning to build almost 40 billion square metres of floor space over the next 20 years, requiring the construction of between 20,000 and 50,000 new skyscrapers, up to the equivalent of ten New York Cities by 2025.[89] Implementing circular economy principles in the early stages of this development could help leapfrog to a restorative and regenerative model that, by design, reduces the cost of accessing goods and services and increases the utilisation of assets. For example, Xiong'an, a state-level new development hub for the Beijing-Tianjin-Hebei economic triangle, will soon have its basic infrastructure and transportation networks built to house two to three million people.[90] This represents great opportunities to implement circular economy principles in urban planning, which would ultimately contribute to higher living standards, positive development, and greater resilience.

By embracing key circular opportunities across the built environment, mobility, nutrition, textiles, and electronics sectors, China could realise a positive transformation in its urban environment, the effects of which would begin to resonate nationwide.

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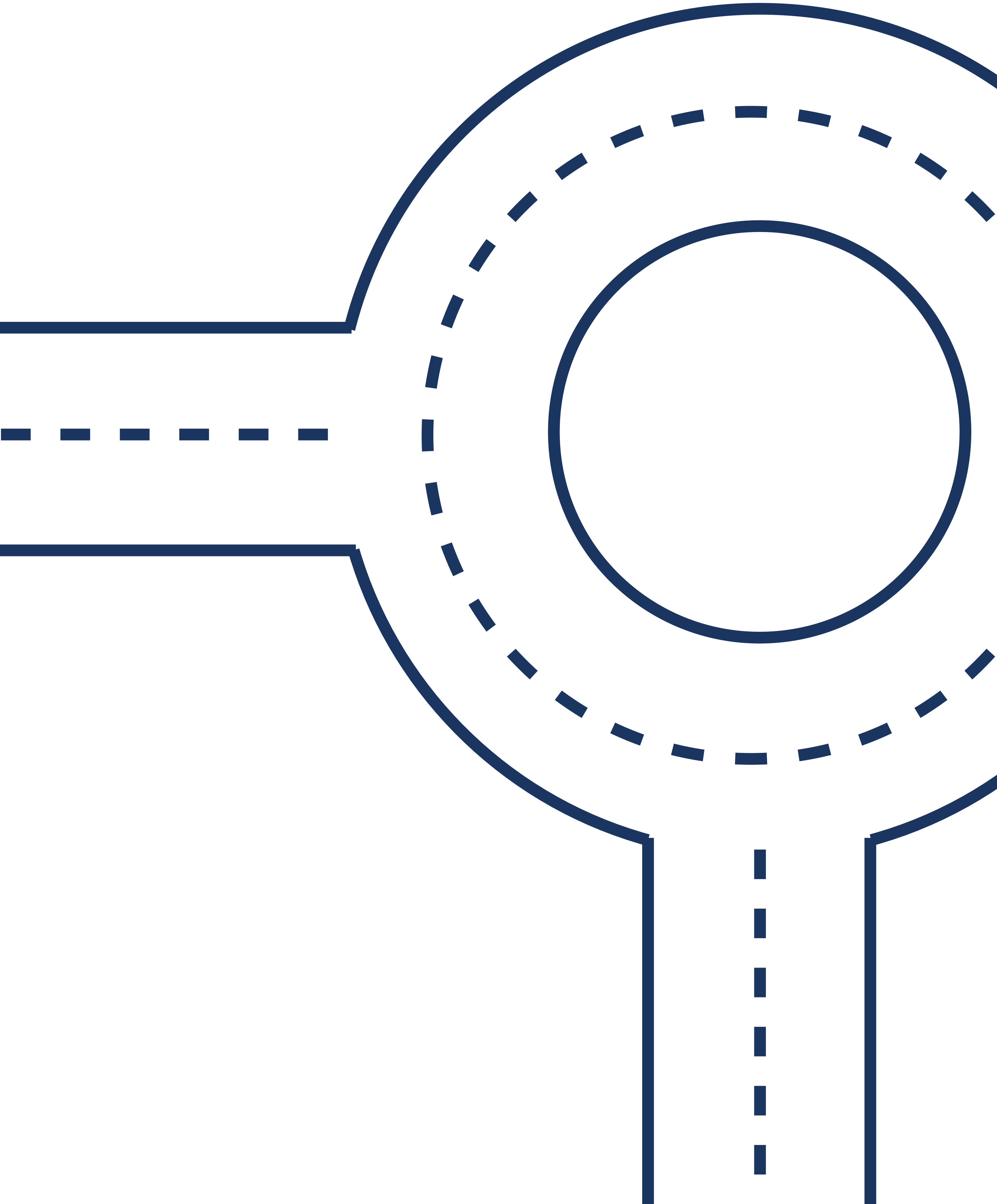
xii We acknowledge the fact that there are many challenges and opportunities in rural China, but for this report we chose the city scope as a starter due to its data availability and ample examples of circular economy implementation and best practices.

xiii Stranded asset risk in the context of circular economy measures has been discussed, for example, in the Ellen MacArthur Foundation report *Achieving Growth Within*, p.37.



2. CIRCULAR ECONOMY - A SYSTEMIC APPROACH

CIRCULAR ECONOMY - A SYSTEMIC APPROACH

A circular economy is a systemic approach to economic development designed to benefit businesses, society, and the environment. In contrast to the 'take-make-dispose' linear economy, a circular economy is restorative and regenerative by design and aims to decouple growth from the consumption of finite resources.

It is based on three principles:

Design out waste and pollution. A circular economy reveals and designs out the negative impacts of economic activity that cause damage to human health and natural systems. This includes factors such as the release of greenhouse gases and hazardous substances, the pollution of air, land, and water, as well as structural waste such as traffic congestion.

Keep products and materials in use. Circular systems favour activities that preserve more value in the form of energy, labour, and materials. This means designing for increased use and utilisation, durability, reuse, remanufacturing, and recycling to keep products, components, and materials circulating in the economy.

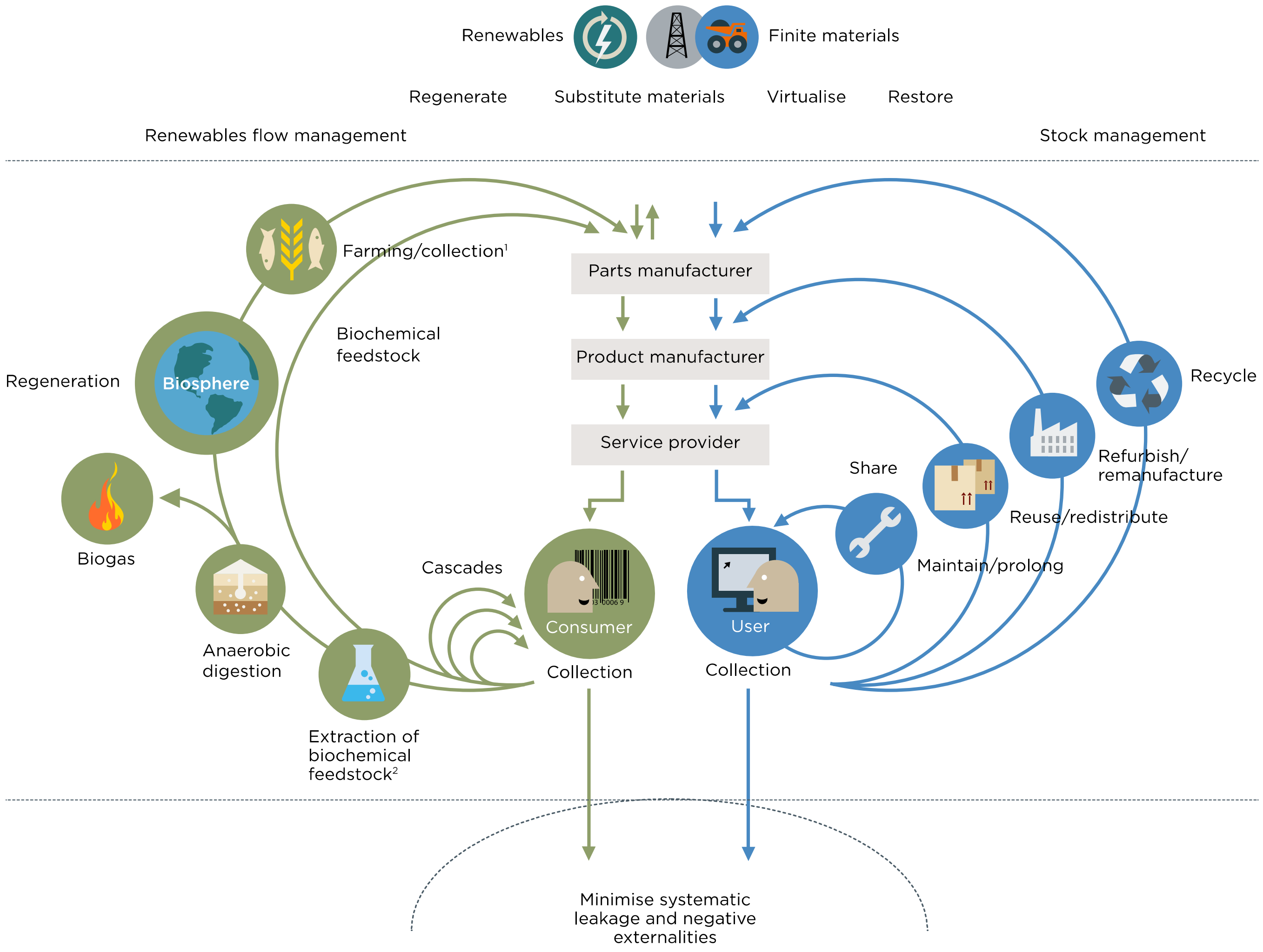
Regenerate natural systems. A circular economy favours the use of renewable resources and their preservation and enhancement, for example, by returning valuable nutrients to the soil to support regeneration or using renewable energy as opposed to relying on fossil fuels.

In a circular economy, activity builds and rebuilds overall system health. The concept recognises the importance of the economy needing to work effectively at all scales – for big and small businesses, for organisations and individuals, globally and locally.

The transition to a circular economy does not only amount to adjustments aimed at reducing the negative impacts of the linear economy. Rather it reflects a systemic shift that builds long-term resilience, generates business and economic opportunities, and provides environmental and societal benefits.

The model distinguishes between technical and biological cycles. Consumption happens only in biological cycles, where food and biologically based materials (e.g. cotton or wood) feed back into the system through processes such as composting and anaerobic digestion. These cycles regenerate living systems (e.g. soil), which provide renewable resources for the economy. Technical cycles recover and restore products, components, and materials through strategies including reuse, repair, remanufacture or (in the last resort) recycling.

FIGURE 1: CIRCULAR ECONOMY SYSTEM DIAGRAM



1. Hunting and fishing
2. Can take both post-harvest and post-consumer waste as an input

SOURCE: Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment; Drawing from Braungart & McDonough, Cradle to Cradle (C2C).

ELLEN MACARTHUR FOUNDATION

Materials recovery

In what is perhaps its most well-known application, the principles of a circular economy can be applied to transform the way resources are used. Currently, most materials are used once, and often for a relatively short amount of time before they are disposed of, at which point their value is lost from the economy. More and more businesses are now realising that it is prudent to keep the resources they use in circulation for longer. For example, a company may recover the products that it creates and sells in order to disassemble the components and use the materials within for the creation of new products. For most, this type of activity should be a first step towards activities with higher levels of circular economy ambition and greater value preservation. The benefits of this approach will be limited without an active engagement in the wider system around individual products. However, collecting assets for their material value can be a starting point, to begin investment in circular economy practices.

Circular design for products

Today, most products are not designed with the principles of a circular economy in mind. Instead, it is more common that items are designed to meet demands associated with a linear production and distribution model, such as cost reduction, speed of assembly, and lightweighting. When the circular economy is used as a guide and goal, the design of the product changes. With this mindset, the priority is for the item to fit within the wider system.

This could mean making a product more durable or easier to maintain, so that it can continue to be used in the 'inner loops' of the technical cycle, such as sharing and reuse. By keeping extra transport, labour, materials or energy use to a minimum, the integrity and value of the item can be preserved. Another possible route is to design a product for multiple consecutive cycles. Rather than aiming simply for efficiency and creating an asset that is light and cheap, manufacturers may initially use more energy and materials to produce an item that can be remanufactured time and time again, using resources more effectively in the long run. Designers can also consider the subsequent uses of their creation by thinking in 'cascades'. This presents options for multiple sources of value creation after the first product has reached the end-of-use phase, with the same or other businesses cascading the resources through many less demanding applications before ultimately recovering the materials. At the stage of material recovery, products and materials should be designed without toxic substances or different materials that are irreversibly fused together, as this decreases the usefulness and hence the value of these resources over time, and could cause further problems in both the technical and biological cycles.

Business models

To unlock greater value in a circular economy, the design of products should be combined with business model innovation. Even if an asset has been designed appropriately – to be durable, repairable, free of toxic materials, and so on – the impact will be severely limited if the business model is not in place to capture the benefits. Again, the type of product, how it is used, and its relationship to the wider system, should be taken into account. For assets in the technical cycle, there is a range of options that can help keep products and materials at their highest value and utility at all times. For instance, durable items could be offered with a deposit to ensure their return, with a resale proposition to redistribute the product to another customer. Some assets can be kept in use for longer through maintenance by the user, as long as spare parts and supporting documentation are readily available. Products of utility like cars, bikes, and power tools can be shared among multiple users, either through a centralised 'library' or via a peer-to-peer platform. Some businesses may choose to move from selling products to servitisation, providing access instead of ownership. By maintaining responsibility for the item, companies can optimise the use of the product, taking care of maintenance, remanufacturing, deployment, and material recovery at the end-of-use (EoU) stage.

While the benefits of such business model innovation will vary depending on the context, there is significant potential to unlock more intense resource utilisation, energy and water savings, and build a stronger relationship with the customer by offering a better service at a lower price.

Circular economy as strategy

The circular economy represents a fundamental shift in the way the entire economy functions. As such, the notion of a 'circular business' is something of a misnomer. However, this does not stop a business using the principles of a circular economy as a lens to guide incentives, investment, R&D, and overall strategy.

Central to the circular economy transition is the shift from activities based on extraction and consumption to those based on regeneration and restoration. It will be businesses that reimagine the way they create value – in line with the principles of keeping products and materials in use, designing out waste and pollution, and regenerating natural systems – that will thrive in a circular economy. At an organisational level, the circular economy can be a strategy for resilience, prosperity, and the contribution to a healthy economic system. A business that is able to decouple its activities from the continual extraction of raw materials by keeping products and materials in circulation, and is powered by renewable energy, is likely to be more resilient to future uncertainty than one dependent on throughput.

Global material flows

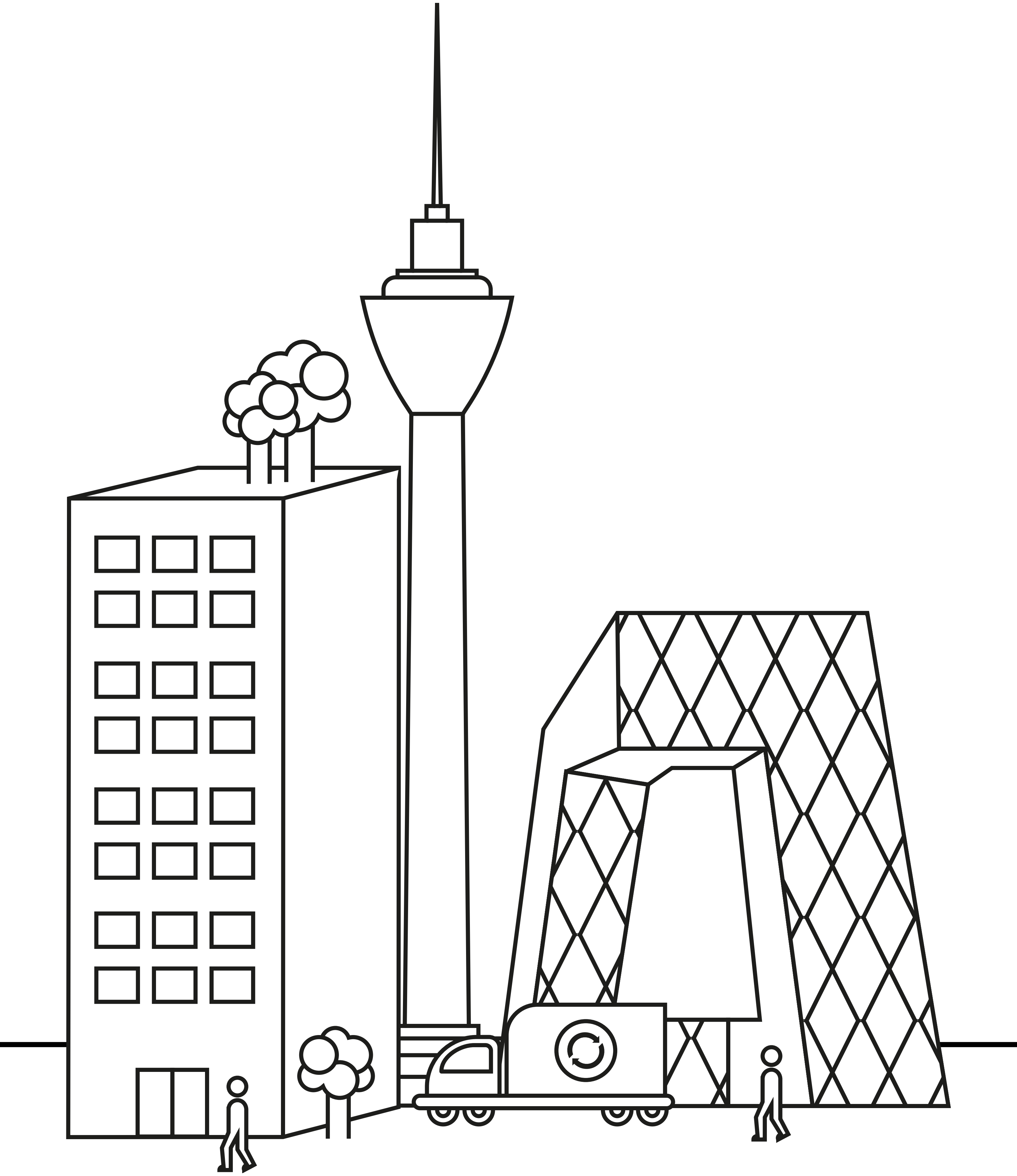
Even with the best intentions, the circular economy efforts of most businesses will be limited if they are pursued in isolation. In order to succeed, organisations will need to rethink collaboration, and work together with others to achieve systems-level change. This means creating new feedback mechanisms between the different stakeholders throughout the value chain. For example, designers and manufacturers will need to work closely with waste management providers, urban planners, and governments to ensure that what they make is not only able to be revalorised, but the relevant infrastructure and mechanisms are in place to make this practically feasible.

Beyond this vertical cooperation, the transition to a circular economy will also require new levels of pre-competitive collaboration. When it comes to the giant, complex materials streams that span the globe, such as plastics, textiles, and food, establishing circular flows will only be possible with commitment from those that have a stake in the way materials are used. Furthermore, some circular economy activities will become more technically viable and economically appealing as a result of pre-competitive collaboration. For instance, if fashion brands and retailers commit to a common garment collection scheme, the greater volumes of material recovered could justify investment in the reverse cycle.

Circular cities

As a lens for systems-level change, urban planners, policymakers, and governmental organisations are applying the principles of a circular economy to guide innovation and create prosperous, liveable cities. Likewise, cities could be uniquely positioned to drive a global transition towards a circular economy, with their high concentration of resources, capital, data, and talent over a small geographical territory, and could greatly benefit from the outcomes of such a transition.

A circular city embeds the principles of a circular economy across all its functions, establishing an urban system that is regenerative, accessible, and abundant by design. These cities aim to eliminate the concept of waste, keep assets at their highest value at all times, and are enabled by digital technology. A circular city seeks to generate prosperity, increase liveability, and improve resilience for the city and its citizens, while aiming to decouple the creation of value from the consumption of finite resources.



3. OPPORTUNITIES IN THREE URBAN SYSTEMS AND TWO INDUSTRY SECTORS

BUILT ENVIRONMENT: DESIGNING BUILDINGS TO BE MODULAR, SHAREABLE, AND REUSABLE

China's urban population is expected to double by 2040, creating substantial demand for new housing and infrastructure. Nationwide in 2016, the built area under construction and completed built area reached 12.6 billion m^2 and 4.2 billion m^2 respectively by the end of the year – representing half of the world's new construction in that year.[91] Many millions of houses will be built in the next two decades and how they are built will determine China's mid- to long-term development. Currently, the country is facing severe challenges from air pollution and construction waste. For instance, in 2013 China generated a billion tonnes of Construction and Demolition Waste (CDW),[92] equivalent to the entire EU.[93] Applying circular economy principles throughout the value chain would help address these issues and provide economic, environmental, and societal benefits. In China's built environment sector,[i] six circular opportunities have been identified at the design, construction, use, and demolition stages: design for longevity; industrialise construction processes; share space to increase asset utilisation; promote green buildings to improve energy efficiency; advocate smart buildings to enhance productivity; and scale up reuse and recycling of construction and demolition waste. Implementing these levers in a coordinated way could unleash remarkable potential in the built environment, creating benefits of CNY 12.4 trillion (USD 2 trillion) in 2030 (compared to the current development path), the largest potential of the five focus areas.

The construction industry is one of the cornerstones of the Chinese economy. In 2016, it represented 7% of urban GDP and provided 50 million jobs.[94] The sector, therefore, has large potential in embracing the opportunities presented by a circular economy to provide even greater economic and societal benefits, while addressing its negative impacts. Such impacts stem from the sector being characterised by design, construction, use, and after-use practices that are resource-intensive and wasteful.

Macro trends are shaping the future of the built environment in China's cities. From 1995 to 2016, China's rapid urbanisation has seen its urban population share increase from 29% to 57%,[95] leading to a substantial rise in urban land area devoted to the built environment. With this trend likely to continue, by 2025 China is set to have 221 cities with more than one million inhabitants and 23 cities with more than five million. If the trend in urbanisation continues at this unprecedented rate, it is estimated that China's urban population will reach one billion by 2030. Government statistics also indicate that cities could soon have a 'floating population' of 147 million, largely made up of migrant workers who often fall within the low-income group, and who all need somewhere to live.[96] Due to this demand, house prices have skyrocketed in urban areas, especially in Tier 1 and Tier 2 cities, and housing affordability has become a major concern of migrants. Lack of affordable housing has meant that some migrants are forced to live in substandard, overcrowded districts, known as 'urban villages' ('chengzhongcun' in Chinese).[97] While low-

i Built environment in this report refers to all residential, commercial, and public buildings in the urban area (excluding public infrastructure), but only the residential buildings are being modelled quantitatively. The lifecycle of a building is taken into consideration from design, materials manufacturing, and construction, through usage, to demolition and landfill stages.

skilled, low-income migrants seek affordable housing, an increasing number of middle-class urban residents aspire to spacious accommodation and higher living standards. Therefore, there is an increasing demand for high-quality housing. The coupling of these demands has resulted in a booming urban residential housing market, which looks set to flourish in the foreseeable future.

Buildings are not designed for durability or flexibility. The average lifespan of a building in China is 25–30 years, whereas in Britain it is 132 years.[98] This difference in longevity is attributable to choices made during the design and construction stages. In China, buildings are only designed to last for about 50 years at the blueprint stage.[99] The designs are generally also very limited in their scope of use, with no allowance made for modularity and adaptability to meet the changing needs of house owners. This short-termism is also prevalent in construction firms, which tend to adopt low-quality materials to reduce the total cost of buildings. Such cost-cutting measures have led to deteriorating housing conditions and other more acute societal impacts. The series of tragedies in Shanghai, Nanjing and Wuhan, in which new apartment blocks collapsed – some even during construction[100] – illustrate this problem.

Traditional construction techniques demand high volumes of primary materials. As in many countries, the construction sector tends to be conservative and cautious of employing innovations in methods, such as additive, off-site, and modular manufacturing.[101] Such reluctance risks continued high consumption (and, ultimately, waste) of primary materials (e.g. China produces and consumes around 55% of cement globally).[102] One consequence of such consumption is high greenhouse gas emissions[103] – China now represents more than 18% of total CO_2 emissions (direct and indirect) in the global buildings sector, having surpassed the EU in 2011.[104]

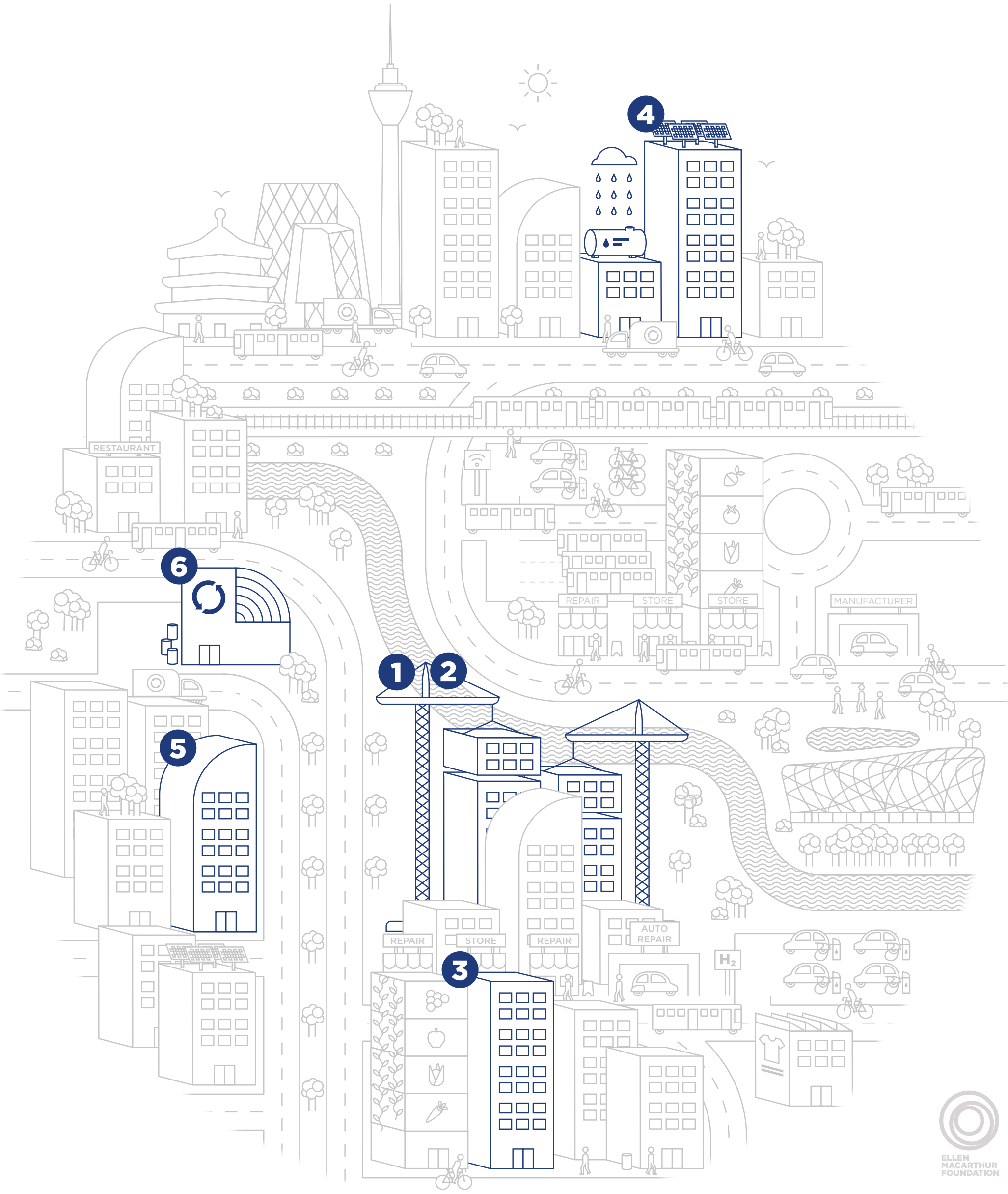
The use phase of buildings is highly energy intensive. From a life cycle perspective, 80% of a building's energy consumption occurs during the use stage, with heating and electronic home appliances consuming the most, at 52% and 30% respectively.[105] In 2012, 16% of total final energy consumption in the global built environment came from China,[106] making the country the second largest consumer after the US. The Ministry of Housing and Urban-Rural Development (MOHURD) has addressed high-energy consumption by issuing compulsory standards, including Residential Building Energy Codes and a Green Building Evaluation Standard,[107] to promote energy-efficient housing. However, the major obstacles of affordability and consumer awareness stand in the way of making a substantial shift in the sector.

Construction and demolition generates high volumes of waste while the recovery rate remains low. Lacking market incentives and policy measures aimed at stimulating waste recovery, China generates high volumes of construction and demolition waste that currently ends up on conventional landfill or dumping sites.[108] According to data from MOHURD, the volume of overall construction waste in China has reached two billion metric tonnes every year and is now increasing by 10% annually.[109] Given the scale of the problem, China's current Construction and Demolition Waste (CDW) recycling rate of 5% is extremely low compared to some other countries, which have rates as high as 95% in Japan, 94% in the Netherlands and 87% in the UK.[110] Furthermore, most of the 5% is reused for road gravel rather than re-entering the construction industry. Meanwhile, the dumping of toxic CDW causes soil and water pollution[111] and air pollution – the dust generated during transportation of CDW to landfill is one of the major sources of PM2.5 air pollution in urban areas.

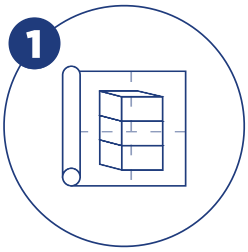
To overcome these entrenched practices in the building and construction sector, a more regenerative and restorative approach is needed. By employing circular economy principles, six opportunities have been identified to generate positive outcomes in the sector, which are outlined on the following pages.

VISION OF A CIRCULAR BUILT ENVIRONMENT IN CHINA'S CITIES

In a circular economy, buildings would be modular, durable, and flexible. The benefits of digitising the built environment would go beyond improving energy efficiency and enhance productivity overall. Embracing a circular built environment would reshape both asset utilisation and material management in the sector. Inhabitants would enjoy better indoor and outdoor air quality.



CIRCULAR ECONOMY OPPORTUNITIES



Design for longevity

Facing the wave of new construction needed in China over the next two to three decades, designing buildings for longevity – including modular, flexible, and durable design – has the potential to create economic, environmental, and societal benefits. New and advanced technologies, including innovative materials, products, and services, are being designed for durability, modularity, repair, flexible upgrade, and disassembly, which could help to reduce maintenance costs and extend the economic viability of buildings and structures, ensuring such assets are used optimally over time. By designing flexible building cores, for instance, developers can enable a building to switch user and purpose later in its use cycle. Buildings designed to be modular and flexible are also easy to disassemble, allowing the materials used in them to retain their value by being reused, reducing waste and the consumption of virgin resources. Park 20|20 is one example of how these principles can be put into practice.[112] The external aluminium frame of the building allows the structure to be disassembled and reused over and over for many purposes. Park 20|20 is designed to reuse waste streams, reduce CO_2 emissions, and minimise material use. The 92,000m^2 of floor space incorporates offices plus services such as a supermarket, nursery, gym, and restaurants. The buildings and surrounding landscape are also specifically designed to add to job satisfaction, increase employee productivity, and inspire creativity amongst Park 20|20's professionals.

Collaboration between all stakeholders is essential for successful design, and digital technology can be important in enabling it. For example, Building Information Modelling (BIM)[113] integrates design, modelling, and planning, allowing architecture design companies to provide all stakeholders with a digital representation of a building's characteristics – not just in the design phase but throughout its life cycle – so the potential for its future uses and cycling of its components and materials can be explored from the outset.[114]

Internationally, increasingly many of these new building designs are emerging. One such project – the White Collar Factory in London's 'Tech City' – is a collaboration between design consultants Arup, developers Derwent London, and architects Allford Hall Monaghan Morris.[115] White Collar Factory is designed to be an adaptable, multifunctional space that incorporates commercial, residential, and public uses. Flexible floor plans and a variety of fittings have been installed upfront to allow for easy division of space, interactivity, and adaptability over time. Such forward thinking should ensure that the building can have multiple use phases.

Industrialise construction processes

The industrial manufacturing of standardised and modular building components, combined with on-site assembly, reduces construction costs, time to completion, and waste. Modularisation could also contribute to lower operational and maintenance (O&M) costs at the end stage of a building as all its components can be easily disassembled and/or replaced. The Millennium Dome project, a retail building in Greenwich, London,[116] which currently houses a wide range of retail outlets and offices, shows the benefit of modular construction with all the modules having been developed so that they can be reused on other sites, maintaining the asset value of the building after deconstruction.

The Broad Group, a Chinese constructor specialising in modular construction, has managed to increase efficiency in production, installation, and logistics six to ten times, with almost zero materials waste and 40% lower total cost of construction through such design approaches.[117] Applying modular construction techniques (see Box 2) the company has built more than 30 factory-based sustainable buildings, and constructed a 57-storey building in just 19 days on site. It is likely that regions such as Beijing–Tianjin–Hebei, the Yangtze River Delta, the Pearl River Delta, and other cities with more than three million permanent residents, will have a high demand for this new mode of construction that offers them the flexibility needed to adapt to a changing urban environment.[118,119]

Another technology that could accelerate the shift to more efficient and industrialised construction is 3D printing (see Box 3) In 2014, the Chinese construction company WinSun 3D-printed and assembled ten 195m^2 houses in 24 hours. Using such technology decreases material use by 30–60%, thereby reducing costs and waste compared to conventional methods. The 'ink' is a mixture of dry cement and construction waste, and WinSun plans to open 100 recycling factories, helping to transform waste into cost-efficient feedstock ('ink').[120]

Alongside new technologies, renewable and local materials could be widely employed in urban construction in the circular economy scenario. For example, bamboo is a fast-growing and sustainable material for houses. Low cost, easy harvesting and light transportation have made bamboo popular again.[121] China, as the biggest bamboo producer in the world, could make the best use of this natural resource. The cost of a bamboo house could be 60% lower than that of a concrete one and be built in a modular and adaptable fashion. Arup, together with GXN Innovation, designed the world's first bio-composite building façade panel. Such an approach could reduce the embodied energy in façade systems by up to 50% compared to conventional construction.

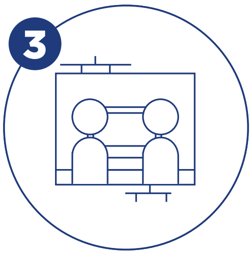
BOX 2: ENABLING MODULAR OFF-SITE CONSTRUCTION AND PREFABRICATION

Industrialisation of the construction industry is not a new concept. It was first introduced in the 1950s, focusing on the standardisation of building designs. From the perspective of circularity, modular construction techniques can reduce the amount of dust and waste generated during the construction process, as well as energy and material consumption. A study has compared two buildings of almost identical structure systems and floor areas in Beijing – one was constructed by a conventional approach, the other had around 38% of total concrete volume prefabricated. The study concluded that prefabrication could reduce energy consumption (20%) and pollutant emissions, such as sulphur dioxide (11%) and nitrogen oxides (4%). Despite steel consumption remaining unchanged and concrete consumption increasing by 10%, it reduced the consumption of other materials by 26–83% and waste generation by 25–81%, depending on the material types.[122]

The Chinese national government aims to have prefabricated buildings accounting for 30% of new build by around 2026.[123] In order to achieve this goal, MOHURD has identified a list of demonstration projects for prefabricated buildings, aiming to promote the development of this technology. For instance, in Jinan city (Shandong province), prefabricated concrete components have been adopted in public affordable housing, private residential, and commercial projects. Prefabricated steel structures have also been used in a primary school and a private residential project.[124]

BOX 3: ACCELERATION OF 3D PRINTING IN THE BUILDING SECTOR

3D-printed garden villas were unveiled in a Suzhou Industrial Park in 2016 bringing attention to their creator, Shanghai WinSun Decoration Design Engineering Co. The buildings were created by using the 6.6m by 10m tall printer with 'ink' from a mixture of glass fibre, steel, cement, hardening agents, and recycled construction waste. One of the six-storey villas, with a floor area of 1,100m^2, was printed in one day and assembled in less than a week, using 30–60% less construction material and costing around 50% less than conventional building methods.[125] This technology also generates fewer negative environmental impacts and the end product is of higher quality due to the use of more consistent materials. Despite the advantages of 3D construction, the practice has not been widely adopted. One reason is that the public is sceptical of such 'too good to be true' technology and are concerned about its safety. Alongside the development of safety standards for the industry with MOHURD, WinSun is now actively trying to promote its technology (it has more than 136 national and international patents across its various product lines) to designers, architects, and developers. It is also involving the public, by giving factory tours, building an open cloud of its products, and erecting another 100m-high demonstration building near Shanghai.[126]



Share space to increase asset utilisation

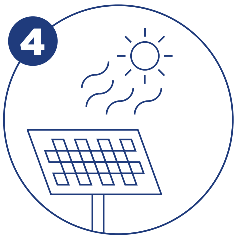
The property boom in Tier 1 cities has been shifting to Tier 2 and Tier 3 cities in recent years, creating a high demand for construction in these areas.127 However, in some new communities, every second apartment is underutilised by its residents.128 Space sharing could provide a good way of improving utilisation without requiring new construction. The space-sharing market in China is growing fast. In 2016, the total turnover in hospitality and office sharing was CNY 24.3 billion (USD 3.9 billion) – an increase of 131% from 2015.[129]

A number of Chinese and international companies have successfully established platforms to satisfy the demand for greater flexibility in the work environment. The public is no stranger to platforms, such as Airbnb, that adopt a customer-to-customer (C2C) model to rent out underutilised residential space, and the adaptation of such models to the working environment is gaining ground. In the office-sharing market, co-working schemes provide options for freelancers, entrepreneurs, and start-ups to have a small office in a central business district with cheaper rents, flexibility, and access to office facilities. A number of international and domestic companies have entered this market and opened offices in large cities, including SOHO 3Q, UR Work, Naked Hub, People Squared, WeWork, WE+, and COWORK.[130] The cost for the most basic desk in such schemes can be as little as CNY 1,000 (USD 160) per month, making it a very competitive option. These co-working spaces tend to offer additional benefits to conventional office rentals, such as help in building connections between their users through networking events – a feature very appealing to entrepreneurs.

Under the Mass Entrepreneurship and Innovation Campaign, the Chinese national government supports start-up companies with subsidies and simplified registration procedures.[131] They are particularly keen to encourage the growth in co-working spaces and incubators, believing that such environments play an important role in nurturing innovation.[132] Some companies, including WE+ and COWORK, are specialising in this area and offer a digital platform on which users can network with each other and seek collaboration opportunities.[133] Many of China's cities are also active in implementing a co-working agenda. For example, the Hangzhou government provided a subsidy of CNY 200,000–300,000 (USD 32,000–48,000) annually for each co-working space in 2015–17, encouraging the organisation of activities for start-up companies and supporting the establishment of the Hangzhou Co-working Space Alliance.[134] There are now more than 100 co-working spaces in Hangzhou, serving over 2,300 companies.[135] With the start-up boom in China (on average, there were 15,000 new company registrations every day in 2016),[136] the office-sharing model has rapidly expanded in Tier 1 cities, including Beijing, Shanghai, and Guangdong province, and has now started to expand into smaller cities, such as Suzhou and Urumqi.[137]

In the market for using houses and flats as holiday accommodation, Tujia has developed its own business-to-customer (B2C) model to better cater to the needs of Chinese tourists, which are substantial – China National Tourism Administration data shows that 4.44 billion domestic trips were made in China in 2016,[138] in part due to the higher disposable income of the emerging middle classes and improved public transport infrastructure. Employing their own, or third-party, property managers, Tujia verifies the quality of its registered properties through on-site inspections, providing assurance to, and establishing trust with, its user network. Xiaozhu has also established a strong market presence – a platform offering daily or short-term room rentals – with offices in over 20 of China's major cities and a list of over 350,000 properties.[139] Its highly tailored prices, which depend on facilities, coupled with its well-connected locations and flexible leases, have made it very attractive to young people.

There is huge potential for this market to develop further. From the supply perspective, property-sharing platforms provide opportunities for millions of small property owners to earn extra income from their underutilised assets – the daily rental rate for properties in Tier 1 and 2 cities could reach CNY 350–500 (USD 56–80).[140] On the demand side, increased appetite from tourists for accommodation and more authentic travel experiences has fostered the growth of this market. Unlike large chain hotels, one of the major selling points of property-sharing platforms is their offering of diverse facilities and experiences to meet the needs of modern tourists.



Improve energy efficiency through 'green buildings'

Green building innovation offers great potential not only for buildings that have minimal running costs, but also enhances the health and wellbeing of their users. According to the Assessment Standard for Green Building report,[141] green building is the practice of creating structures and using processes that are environmentally responsible and resource efficient throughout a building's life cycle. The benefits of green buildings are reflected in lower energy and water usage, and reduced O&M costs. Indeed, green buildings have the potential to bring down energy consumption by 30–50%.[142,143] For example, Building Integrated Photovoltaic (BIPV) and grid-connected generating technologies could be a solution for solar energy utilisation in China's densely populated cities. The world's largest standalone building with an integrated PV system is in Shanghai Hongqiao Railway Station. More than 20,000 solar panels on the 61,000m^2 roof produce 6.3 million kilowatt-hours (kWh) of electricity annually.[144] Rolling this technology out further would form an important part of the energy plan for a circular city. Grey water technology should also be a primary focus to address the issue of China's ever-shrinking supply of drinking water. The potential here is significant, as buildings account for 60% of China's wastewater, of which 70% can be classified as grey water (i.e.. clean, non-faecal wastewater) that can potentially be reused. Moreover, through rainwater-harvesting systems, such as roof gardens or rainwater cisterns, rainwater could be collected for use in the building.

In China's major cities such as Beijing, Shanghai, and Shenzhen (see Box 4) the green buildings market is already mature. However, buyers of real estate in Tier 2 or Tier 3 cities tend to have lower than average income levels and there are fewer local incentives for efficiency, making green buildings a less attractive option, both for buyers and developers. Certified green buildings come with a purchase and rental price premium of 26% and 28% respectively.[145] This discrepancy has created a 'green gap' between Tier 1 and other cities, which represents an opportunity for future green building hotspots in Tier 2 and Tier 3 cities, if the right enablers are put in place.

One concrete example of green building in China is the passive house[i]. Passive houses are dwellings that require very limited energy for space heating or cooling. Compared to traditional houses, passive houses save 80% of heating energy and 50% of energy for cooling and dehumidification. Research has proven that passive houses are feasible in all different climate zones in China.[ii,146] However, currently only a minority of new buildings are passive houses, so there is a clear case for development here that could be economically and environmentally beneficial.

i Passive house is a rigorous, voluntary standard for energy efficiency in building, reducing its ecological footprint. Passive building employs superinsulation to significantly reduce the heat transfer through the walls, roof and floor compared to conventional buildings.

ii Due to its vast size, China covers six different climate zones which are Cold-Temperate Zone, Warm-Temperature Zone, Temperature Zone, Subtropical Zone, Tropical Zone, and Qinghai-Tibet Plateau Temperate Zone.

BOX 4: GREEN BUILDINGS: CIRCULARITY THROUGH DESIGN

The Shenzhen Stock Exchange Square, commissioned in 2013, was awarded a three-star rating under the Green Building Evaluation Label (GBEL) developed by MOHURD. The 245m-tall landmark building incorporates various green building designs, including a self-shading façade that passively shades the building and reduces the need for window vents; a schematic design for comprehensive water resource utilisation; a solar water-heating system; and an energy-efficient water-cooled air-conditioning system. These features result in a high level of resource efficiency, with 40% water and 20% energy savings over conventional design code[147] Green buildings not only maintain or improve environmental quality, but also reduce operational cost through the building's very design.

Another such example is the tallest skyscraper in China (at date of publication), Shanghai Tower, which displays a series of green technologies. The building achieved both three-star certification under GBEL and a platinum rating in Leadership in Energy and Environmental Design (LEED) for its core and shell.[148] Its rooftop wind turbines could generate up to 10% of its electricity consumption. It is also equipped with double-layer insulated glass; a combined cooling, heat, and power system; a rainwater harvesting system; and a grey water recycling system.

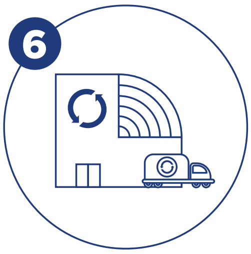
BOX 5: SMART WATER SYSTEMS

The resource opportunity from using sensors, communication technology, and data analytics is not limited to the built environment. Another key component of urban infrastructure – the provision of drinking water – is prone to major resource losses because of unaddressed – and often under-assessed – leaks in the piping system. This problem is compounded by low specification meters that fail to gather data about actual consumption and losses. The reality of this lack of data was shown in a 2015 survey of 603 of China's cities that revealed the total excess of water supplied over total water meter consumption readings was 21% or 8,600 million m^3. Smart metering transmits regular data on water flow in pipelines, highlighting unusual consumption patterns, which allow for much quicker identification of when and where leaks are occurring. Increased metering accuracy also enables more effective revenue collection by eliminating billing estimates. Cost savings are further increased as manual readings and billing are no longer required. Shenzhen Water, a state-owned-enterprise (SOE), has comprehensively upgraded its water management system to embrace smart metering technology by deploying approximately 1,200 narrowband (NB) IoT-enabled smart water meters for Southern Pearl Garden and other residential areas in the Yantian District of Shenzhen.

The true power of smart water systems can be illustrated by their success in industrial facilities worldwide. The IBM factory in Burlington, Vermont, US installed a system that measured the characteristics of the water flowing through the facility. The system comprised 5,000 electronic sensors collecting 400 million data points a day, covering 80 parameters (including temperature, flow rate, pressure, pH, and clarity). The analytics allowed IBM to sift for patterns and trends, looking for bulges of energy and pressure that were not being used. The result was that between 2000 and 2009, IBM cut its water use by 29% or, in financial terms, CNY 4.5 million (USD 0.72 million) per year. Added to this, they saved CNY 4.2 million (USD 0.67 million) in chemical and filtration costs, and CNY 19 million (USD 3 million) in energy and electricity. Off the back of this initiative, IBM developed a whole new business around smart water management. If this type of technology could be applied in a residential urban environment, it would provide stakeholders with very accurate information, leading to a better understanding of resource use, including where surpluses and deficits exist, and the potential for synergies, efficiencies, and savings.

Enhance productivity with 'smart buildings'

The concept of a 'smart city' is gaining traction in China thanks to the development of digital technology, in particular the Internet of Things (IoT). Smart building technology – such as sensors, data storage, and computing services – is a prerequisite of the smart city concept and is increasingly part of people's day-to-day lives. Smart meters for electricity and gas allow residents and owners to make informed decisions about their energy usage and can result in substantial cost savings. For example, the smart lighting system in Shanghai Tower can achieve an annual energy cost saving of CNY 3.88 million (USD 0.62 milion). In smart buildings, data analytics are applied to optimise a building's energy and water management (see Box 5). Swedish construction and development company Skanska AB, for instance, uses sensors to record data such as temperature and vibration, and wireless equipment to store and transmit the data. The use of such smart-equipment technologies could result in a 40% reduction in electricity use and an 87% reduction in gas consumption.[149] Scaling up such technology could see measurable improvements in energy efficiency and productivity throughout China's built environment.



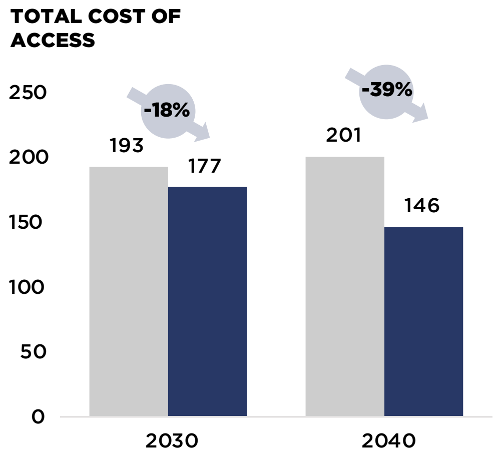
Scale up reuse and recycling of construction and demolition waste

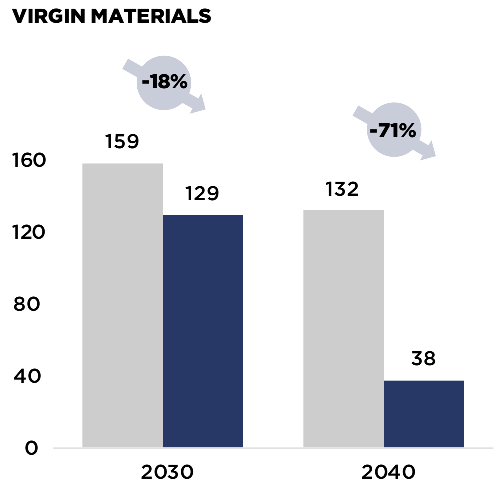
While the construction of a 10,000m^2 building will create 500–600 tonnes of waste, its demolition will create 7,000–12,000 tonnes of waste, so there is a clear need to address the after-use phase of buildings. Construction and demolition waste (CDW) in China consists of concrete (48%), brick and block (21%), ceramics (10%), and other materials (21%).[150] Those discarded materials could be recovered and reused in a variety of ways, such as for gravel, road building materials or flooring. Take concrete as an example – it is a durable building material that is also recoverable. Recovered concrete from CDW can be crushed and used as aggregate. It can also be recycled and reused in new concrete.[151] Maximising the use of repurposed materials and components in this way would reduce the need for virgin materials and would cut the pollution caused by CDW in the urban environment.

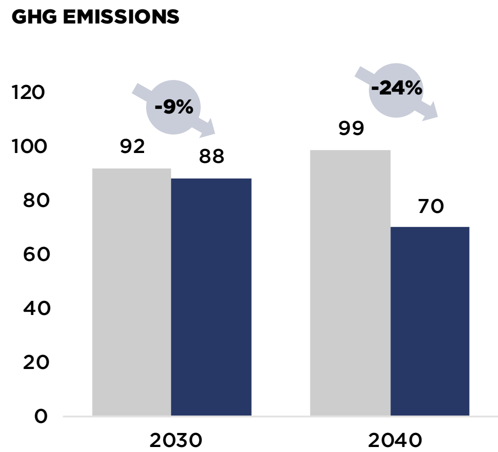
Today, most common building materials have recyclable alternatives. In China, tiles, bricks and bamboo are traditional materials that could be used more, even in new buildings. Chinese architects are already finding ways to incorporate such construction heritage and tradition into their designs.[152,153] Ningbo History Museum is one example of this trend. Developed in partnership with local craftsmen,[154] it was made from a mix of raw materials and those leftover from the demolition of old villages. This blend reduced the need for expensive virgin materials in the construction process, and, at a later point, the materials can be potentially cycled again, decreasing costs and the building's environmental footprint.

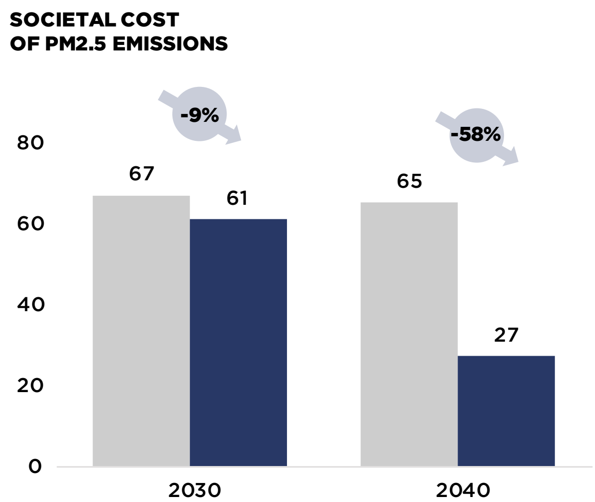
A CIRCULAR BUILT ENVIRONMENT: THE BENEFITS FOR CHINA'S CITIES

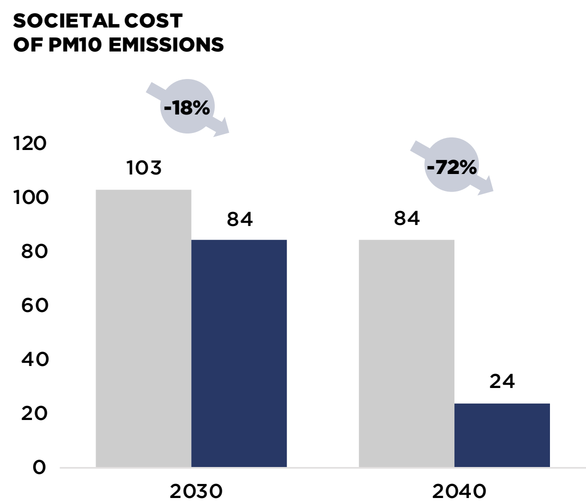
Current development path   Circular economy path   Index 2015 = 100











CALCULATING THE BENEFITS

Current development path
On the current development path, the average size of an urban residential apartment per household is expected to increase from 60m² in 2015 to 90m² in 2030,[155] due to the increasing demands for space from China's emerging middle class. In line with the 13th Five Year Plan and specific government building construction policies, it is assumed that the government would put more emphasis on improving energy efficiency and combatting environmental pollution. It is predicted that a huge amount of financial support could be invested in affordable housing in cities to offer a decent living space for low-income families and immigrants. In this scenario by 2030, 50% of urban new builds would be green buildings, 30% of CDW in cities would be recycled and reused, and 20% of urban buildings would be built using industrialised construction processes, such as prefabrication or 3D printing.

Circular economy path
In a circular economy scenario, the identified opportunities impact different parts of the value chain, interacting and amplifying each other's effects on the overall built environment. The buildings are assumed to be designed for longevity, be shared widely, built by industrialised construction, and make use of using smart home/office technology. Durability, modularity, and shareability are the key attributes of future buildings. In this scenario by 2030, 70% of urban new builds would be green buildings, 60% of CDW in cities would be recycled and reused, and 25% of urban buildings would be built using industrialised construction processes, such as prefabrication or 3D printing.

Embracing all six opportunities could yield a 17% reduction in total cost of access (TCA)[iii] by 2030, and by 2040 the impact would rise to 39%, representing savings of CNY 34.5 trillion (USD 5.5 trillion). In 2030, 97% of savings are reductions in user cash-out costs, with the remaining 3% reductions in the cost of negative environmental externalities such as CO_2 emissions and particulate emissions (in 2040 this split is 98% and 2%). In addition, scaling up reuse and recycling would see 32 billion tonnes of urban CDW recycled by 2040. Due to waste reduction, the landfill volume could be cut by 81% in 2040 when compared with the current development path.

In 2040, user cash-out costs – which include the construction and demolition of buildings and their running costs to households and other users – could be 39% lower in the circular scenario than under the current development path.

In 2040, the cost of building construction in a circular scenario could be 61% lower than that in the current development path. This cost reduction is mainly due to improved resource productivity in the construction phase, driven by the adoption of industrialised construction technology, increasingly coupled with on-site modular assembly. These innovations could be augmented by a transition to re-using and recycling CDW rather than using raw materials for new construction, resulting in a significant drop in material costs.

The benefits of this transition are not limited to lower costs for developers and builders, but extend to residents who benefit from reduced running costs and maintenance expenditure. Indeed, in the urban setting, O&M costs would reduce by 10% in 2030 and 28% in 2040, compared with the current development path. Specifically, household energy bills – including electricity, gas, fuel oil, and water – would be dramatically reduced in a circular economy scenario because of the rise in green and smart buildings. These long-term benefits can, with the right financing mechanisms, outweigh the additional upfront investments, making them attractive to investors.

Compared to the current development path, CO_2 emissions could decrease by 24% in 2040 and particulate emissions by 61% in 2040.

iii Total cost of access (TCA) is made up of cash-out costs and externality costs. Cash-out costs exclude government subsidies and incremental capital expenditure (the added investment needed to move to the circular economy scenario). Externality costs represent the economic costs, such as lost earnings and healthcare expenditure, associated with, for example, emissions of greenhouse gases and particulates. Details can be found in the Technical Appendix.

CO_2 emissions could decrease by 9% in 2030, and by 24% in 2040, compared with the current development scenario. The reduction is driven by promoting green building technologies, smart buildings, and space sharing. Green building contributes 85% of CO_2 emissions reduction in 2030 and 89% of CO_2 emissions in 2040. Similarly, particulate emissions (both PM2.5 and PM10) could decrease by 11% in 2030 and by 61% in 2040. These reductions would be driven by increased use of additive manufacturing and off-site construction such as prefabrication, which would minimise the construction dust that makes up the majority of PM10 emissions.

Adopting advanced construction technologies as well as reusing and recycling CDW could reduce virgin material consumption in China's urban built environment by 18% in 2030 and by 71% in 2040.

In a circular scenario, virgin material consumption drops 18% in 2030 and 71% in 2040, when compared with the current development path. In 2030, this reduction is driven by space-sharing opportunities, which increase building utilisation. In 2040, scaling up reuse and recycling of CDW would further decrease the level of raw material consumption.

Increasing the recycling and reutilisation of CDW also significantly reduces the need for virgin materials.[156] The 'Bulk Solid Waste Utilisation Action Plan'[157] issued by the NDRC has set the target that construction waste reutilisation in large- and medium-sized cities should reach 30%. The focus of these policies is on addressing resource inefficiencies at several stages across a building's use cycle. On top of this policy, a circular scenario enables the use cycle of a building to be extended by looping or cascading building components and materials into new uses.

MOBILITY: SHIFTING THE FOCUS TO MOVING PEOPLE NOT VEHICLES

In the last 30 years, China's increasingly urbanised and affluent population has created an explosive demand for personal mobility with many citizens considering the ownership of a car as a status symbol. In just over two decades, the total car stock in the country has increased by a factor of more than 11. As a consequence, many of China's cities are among the most congested and polluted on the planet. The negative economic, environmental, and human health impacts of this situation threaten to slow China's development, unless the mobility sector embraces a systemic shift to a more regenerative and restorative approach. Our analysis has identified five key circular economy opportunities to accelerate this transition: facilitate shared and multi-modal mobility; scale up remanufacturing and use more recycled materials; design vehicles to fit a circular mobility system; scale up zero-emission forms of propulsion; and encourage remote and flexible working. Embracing all five circular economy opportunities could reduce the total cost of access (TCA) of mobility by CNY 12.6 trillion (USD 2 trillion) in 2030. Circular economy opportunities could reduce congestion costs by 36% in 2030 and 47% in 2040. Additionally, the costs of fatalities and serious injuries from road accidents could be reduced by 20% in 2030 and 28% in 2040. Implementing and integrating all of these circular solutions would result in a vibrant mobility sector that not only offers greater choice to the user, but is also more economically and environmentally viable for China's cities going forward.

China's swift economic expansion and urbanisation has led to unprecedented growth in the number of cars in its major cities. The total car stock in China grew from 16.1 million in 2000 to 172 million in 2015[158] and it has been estimated that it will exceed 200 million by the end of 2020.[159] Such rapid growth does not come without consequences. Ten of the world's 25 most congested cities are in China.[160] According to a study by the global finance firm UBS, there are on average around 200 cars for every kilometre of road in China, equal to Los Angeles, which has some of the worst traffic in the US.[161] Such a high volume of traffic not only makes the lives of urban residents more unpleasant, but also more inefficient when commuting – in 2017 the average 17.4km journey to work in Beijing was taking up to 52.9 minutes, in Dongguan and Shenzhen, two cities in Guangdong Province, the figures were 48.5 minutes for a 17.3km journey and 47 minutes for 16.8km, respectively.[162] At the same time, vehicle ownership levels are still below the global average of 140 vehicles per 1,000 people. Indeed, in 2015, the level of car ownership in China reached 120 vehicles per 1,000 habitants – the same level as the US in 1920. In major European countries, ownership currently stands at 550–600 per 1,000 and at 825 per 1,000 in the US.[163] If China would like to reach parity with the US on this front, it would have to put an additional 1 billion cars on its roads.[164]

The high volume of traffic in China's cities has negative impacts on citizens' health and the environment. Air pollution has become a major environmental and societal concern in China – fewer than 1% of China's 500 largest cities currently meet the air quality standards recommended by the World Health Organisation (WHO).[165] This poor air quality has been linked to rapidly increasing cases of cardiovascular diseases and lung cancers.[166] Recent OECD reports suggested that, in 2010, the health impact of outdoor air pollution in China was approximately CNY 10.6 trillion (USD 1.7 trillion), roughly one third of which can be attributed to mobility.[167] As well as local air pollution, China's mobility sector is a large source of CO_2 emissions. These emissions were estimated at 623 million tonnes in 2011, accounting for about 7.5% of the country's total, and on their current trajectory they will only continue to rise.[168,169] There are also more immediate dangers – according to WHO, at least 200,000 people in China die every year as a result of road accidents.[170]

China's cities are actively taking measures to address the negative impacts of the current mobility system. In an effort to combat the issues surrounding congestion and pollution, an increasing number of China's cities are implementing policies that constrain passenger vehicle ownership and use, with a view to limiting the number of cars on the roads. Some policies are based on economic incentives, such as increasing standard parking fees, while others are based on administrative orders. For example, Shanghai issues 9,000–10,000 new licence plates a month, auctioning each at an average price of CNY 82,000 (USD 13,400), which is then added to the purchase price of the vehicle.[171] With an increasing number of cities imposing such caps on car registrations, the growth of new private vehicles sales in China is expected to decelerate.[i, 172]

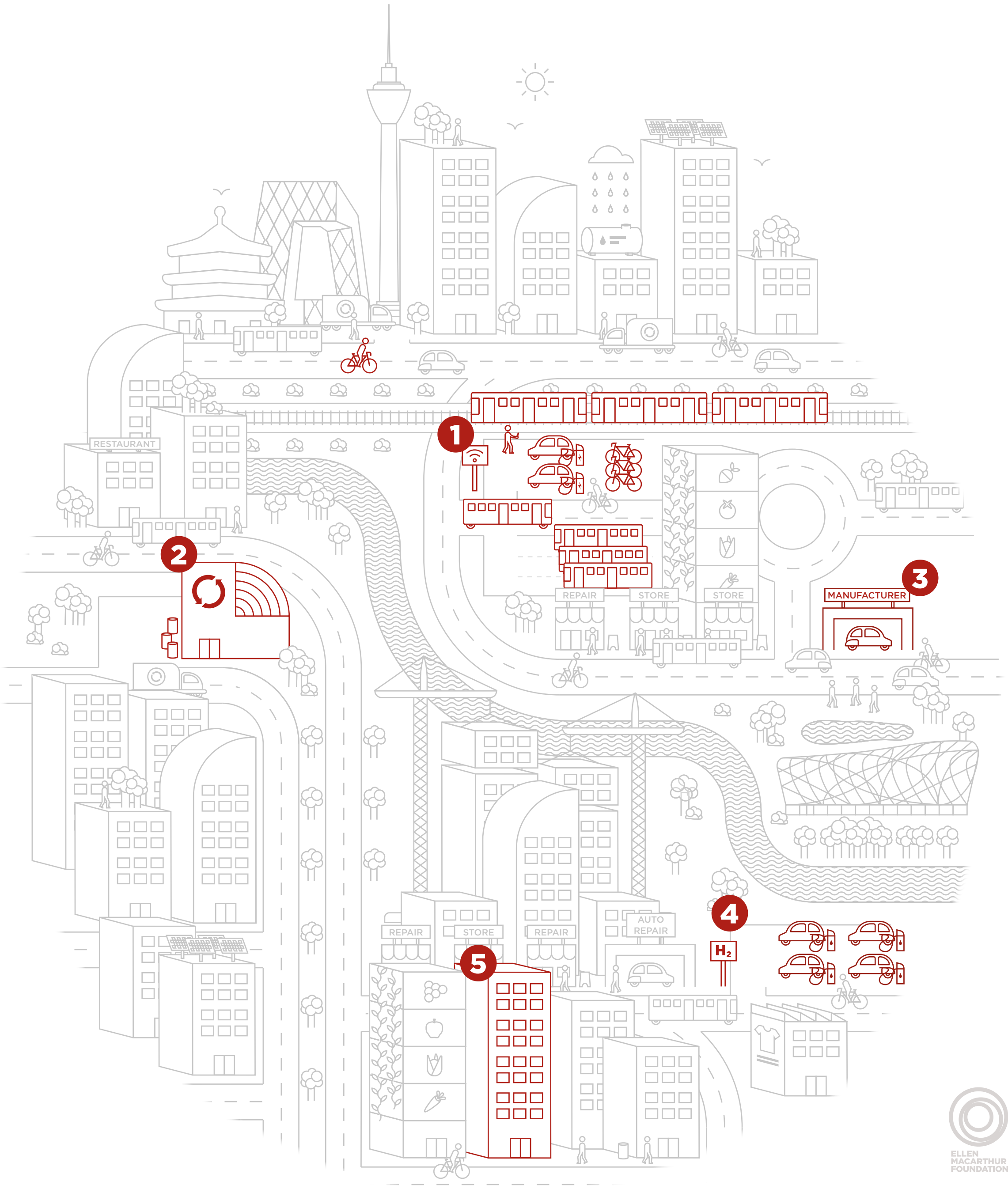
Trends are emerging that indicate users are ready to embrace shared mobility. Despite car ownership still being associated with social status in China, for many inhabitants of the country's mega-cities, it is losing some of its appeal. Currently, urban citizens in China mostly value safe, punctual, flexible, and reliable mobility, not necessarily based on the private car. A 2015 survey shows that up to 30% of current car owners in China's mega-cities would consider giving up their cars if congestion were to continue to rise, and air quality continued to decline. Respondents also stated that improved public transport, taxi availability, car rental accessibility, and the emergence of new mobility solutions supported by digital applications, would facilitate them giving up their cars.[173]

Several factors, such as the convergence of disruptive technologies, societal trends, and new business models have started to improve mobility in China and around the world.[174] A broad group of stakeholders, ranging from traditional vehicle original equipment manufacturers (OEMs) to technology companies, such as Alibaba[175] and Baidu,[176] are all working to develop the car of the future. Indeed, in the next two decades, passenger mobility in China's cities is likely to be transformed. Implementing the five circular economy opportunities shown on the following pages could accelerate this positive change.

i China Automotive Dealers Association (CADA) estimates that by 2020, the number of second-hand cars traded will equal that of new car sales at 29.2 million. According to this forecast, 75 used cars will be sold per 100 new cars in 2017 and this ratio will be 1:1 by 2020, which is still significantly below the ratio of two to three used cars per new car among most developed car markets.

VISION OF A CIRCULAR MOBILITY SYSTEM IN CHINA'S CITIES

A circular mobility system in China's cities would be multi-modal and shared. It would have zero-emission vehicles designed according to circular economy principles. It would allow urban dwellers to easily work remotely and flexibly. Integrating all these circular solutions would result in a vibrant mobility sector that not only offers greater choice to users, but also contributes to a more economically and environmentally resilient urban future.



CIRCULAR ECONOMY OPPORTUNITIES

The ever-increasing demand for passenger transport requires a mobility system that addresses users' needs while reducing costs, resource consumption, emissions, and negative impacts on health and society. Mobility in the urban context is an integral part of the whole city infrastructure, so various modes of transport need to be integrated into urban planning, and the needs of other sectors, such as the built environment, must be considered.

Our analysis has identified five key circular economy opportunities that could reshape the future mobility system in China's cities: facilitate multi-modal shared mobility; scale up remanufacturing and use more recycled materials; design vehicles to fit a circular mobility system; scale up zero-emission forms of propulsion; and encourage remote and flexible working. These levers amplify each other and as a result may shift the mobility paradigm faster than current expectations.

Facilitate multi-modal shared mobility

An urban mobility system, tailored to the needs of fast-growing city populations, integrates several types of transport: public (e.g. metro, trams, trains, buses); semi-public (e.g. taxis, shared vehicles); and private (e.g. bikes, cars). 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 new forms of shared transport demonstrates the appeal and potential of a new type of mobility system. However, to realise this potential, a coordinated, coherent, and overarching strategy must be put in place that is tailored to the needs of passengers. Such a strategy could put the shift to a multi-modal mobility system on an accelerated trajectory.

Currently, sharing systems are thriving in China, thanks to smartphones, Big Data and the growing popularity of new business models. A recent survey in China showed that 47% of the interviewees had heard of car-sharing and 76% expressed an interest in it.[177] The sharing of vehicles (including cars and two-wheelers) can take various forms. The vehicles can either be owned and managed by the OEM (such as Daimler's JíXíng car2go model); managed by third parties while supported by OEMs (such as Gofun Chuxing);[178] or managed independently by third-party technology providers (such as peer-to-peer car-sharing platform zuche.com).[179] Within such shared schemes, OEMs or service providers have an incentive to run a fleet of durable, efficient cars with low running costs.[180]

One particular innovator in this space is Didi Chuxing, a pioneer of e-hailing, whose platform allows users to request immediate pick-ups and book taxis remotely, as well as find opportunities for car-sharing, minibus hire, and even bike hire. Didi was founded in 2012, and by 2016 had 550 million registered passengers and 21 million registered drivers/car owners with the daily average number of rides booked through the site totalling more than 20 million.[181] This very large amount of data about passenger demand and vehicle use could help improve mobility management within cities, if underpinned by strong cooperation between government and other businesses.[182]

Another model that has recently become popular in China's cities is bike-sharing. Founded in 2015, Mobike is the world's largest smart shared bicycle operator with a fleet of 3.65 million bicycles in 50 cities, which is used more than 22 million times a day.[183] Mobike and its competitors offer their users a high level of flexibility as the bikes can be parked anywhere after use.[184] Recent reports show that this 'park anywhere' philosophy is taken very literally in China and some bikes are found parked in green spaces or simply piled up like garbage. To address this, local governments are collaborating closely with business to establish regulations.[185]

Public transport is also a form of shared mobility. China's cities are already investing in this area, propelled by local needs and central government mandates. The recently published 13th Five Year Plan covers the development of urban mobility across China's cities with the focus on public transportation from 2016 to 2020. It aims to realise a smart urban mobility infrastructure by 2020.[186] For example, the Beijing metro, which had 18 lines totalling 527km in 2014, is set to expand up to 1,000km by 2020, double the projected length of the London Underground by this date.[187] In 2015, during the US-China Climate Leaders Summit in Los Angeles, China affirmed that by 2020 public transport will account for 30% of motorised urban travel in the country.[188] The Transit Metropolis Programme – a national-level programme covering 37 pilot cities – is designed to help reach this target by encouraging and supporting cities to improve their public transport systems.[189] Further development of public transport would also greatly benefit from well-orchestrated management of the urban built environment, in which the mobility system is embedded. Indeed, a well-designed public transport system can profoundly increase the effectiveness of urban space use (see Box 6).

Another development that could enable multi-modal mobility and offer a step change in personalised transportation is the autonomous vehicle (AV). Within the next decade, AVs could play an important role in the mobility offering, particularly by providing door-to-door and 'last mile' solutions for urban residents. In 2016, China's Ministry of Industry and Information Technology (MIIT) and the China Society of Automotive Engineers announced a detailed roadmap aiming to ensure that highly or fully autonomous vehicles would be on sale in the country by 2025.[190] A network of connected AVs could reduce congestion and allow citizens more productive time due to their potential for increased road utilisation and better traffic management. Fully automated vehicles could also potentially reduce the number of road traffic injuries and fatalities.

However, at this stage it is too early to have a complete understanding of the benefits and challenges of AVs as the technology is still under development and safety testing. Indeed, a recent study suggests that increased demand for easy and cheap access to mobility could lead to a growth of 25% in passenger kilometres travelled by 2030, with the majority of these additional distances attributable to last-mile solutions provided by AVs.[191] Therefore, development of AVs could be supported by legislative boundaries to mitigate potential negative effects. AVs could also benefit from other changes in legislation, for example, transferring the responsibility of an accident from the driver to the car manufacturer when a car is in self-drive mode. Additionally, to implement AVs at scale, a high-tech and extremely detailed mapping of a city is required, which is not currently available to the same degree in all of China's cities. Nevertheless, such new advances do present an opportunity for a more flexible and tailored transport system that could alleviate the pressures on China's roads.

BOX 6: FROM PARKING SPACES TO TRANSIT-ORIENTED DEVELOPMENT: SYSTEMS THINKING IN MOBILITY

In line with improvements in incomes and living standards, cities in China are experiencing a surge of private car purchases. By 2015, in large cities such as Beijing, 60% of households owned a car and the trend is expected to continue.[192] A significant gap between the numbers of cars and the provision of car parking spaces is already appearing – the ratio of cars-to-parking spaces is 1:0.8 in big cities and 1:0.5 in small and medium cities.[193] This deficiency is further aggravated by the underutilisation of existing parking spaces as parking space owners often leave their private lots locked and empty during the daytime when they are parked away at work.[194]

In response, various parking space sharing solutions have started to appear on the market. For example, Ding Ding Ting Che in Beijing utilises smart car park locks that can be raised or lowered by a smartphone app with the use of Bluetooth technology. The system serves as a car park sharing platform, where private parking lot owners can rent out their spaces (when not in use) to other registered app users.[195] This sharing scheme works best in urban multifunctional areas where both residential and commercial activities occur so there is a complementary parking demand. For the city, the platform helps relieve parking shortages and improve space utilisation. Studies in North America have shown that shared parking systems need 20–40% fewer parking spaces.[196] Creating a win-win situation for both drivers and parking lot owners, this sharing initiative is expected to grow.

As well as building more parking spaces, cities like Beijing have capped the number of new licence plates issued every year and imposed various caps to keep non-local private vehicles from entering the city.[197, 198] Effective as these regulations may be at stopping the current situation from worsening, the power of design could be leveraged to address the root of the problem, i.e.. reducing the demand for cars. Urban planning can play an important role in promoting the use of public transport and suppressing the need for private vehicles. This is particularly relevant for the new cities currently planned in China. The Transit-Oriented Development (TOD) principles offer a good example, advocating high-density, walkable, and mixed-use urban development around public transit nodes.

TOD promotes walkability and allows better integration of non-motorised transport with public transport, which in turn could discourage the use of private vehicles. A Chinese study revealed that such urban schemes could reduce CO_2 emissions per capita by 38–53% by 2030, with the benefits particularly evident in cities with populations of 1 million or above.[199] The schemes could also reduce PM2.5 emissions, as well as congestion issues and parking space deficiencies. Chenggong District in Kunming City adopted TOD for their master plan in 2009, which split the area into numerous multi-functional small blocks, linked by easily accessed rapid bus transit, metro, and high-speed rail links. Chenggong's goal is to complete 90% of its development within 500m of bus stations.[200] The plan also features easily accessible open spaces and communities that are bike- and pedestrian-friendly.

To realise the benefits of such a large-scale project, cooperation between the municipal government, urban planning agencies, and real estate developers is crucial. Urban planning and transport infrastructure are the backbones of a city's development, and continued governmental support of the TOD principles is critical as it often takes decades to turn urban planning blueprints from paper to reality.

CASE STUDY 1: MULTI-MODAL MOBILITY IN YICHANG

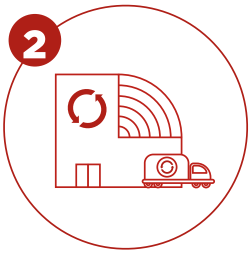
Yichang is a mid-sized city on the Yangtze River with an urban population of around 2 million.[201] While there are many similar-sized cities in China, Yichang has been an exemplar in the field of innovative transportation. A bus rapid transit (BRT) of 24km spanning the city from north to south forms the backbone of the city's mobility infrastructure. The corridor runs through the downtown and connects the major transport nodes for trains, high-speed rail, and long-distance buses. With features such as dedicated BRT lanes, off-board fare collection, and pavement level boarding, the system provides a smooth experience by improving boarding efficiency and travel speed. BRT currently hosts 240,000 passenger trips every day and has reduced the distance the city's private cars travel daily by 300,000 km.[202] A survey has revealed a remarkable shift from private vehicles to public transport since the BRT system was put into operation. The percentage of journeys travelled by private vehicles dropped from around 42% to 30%, while the share of bus and BRT journeys rose from around 18% to 32%.[203]

Another critical attribute of the success of Yichang's BRT is its integration of bike- and pedestrian-friendly facilities for last-mile transit. The municipal government is setting up a public bicycle system with bike points distributed around the city centre area at 400m intervals to connect BRT stations to their surroundings.[204] The pedestrian environment along the BRT route has been improved by the clearance of obstructions/impediments, and the provision of more green space, covered walkways, artworks, and urban furniture. These additions alleviate the annoyance caused by surrounding traffic and the weather, while improving overall aesthetics. Improved road-crossing facilities have enhanced safety and the user experience. All these changes have made the areas along the BRT route more attractive, accessible, and people-centric, promoting the use of non-motorised transport for last-mile short trips and public transport for longer journeys.

Finally, societal acceptance and support are key to a wide adoption of such integrated public mobility schemes. For BRT to become a favoured mode of transport, speed is not the only consideration – a pleasant user experience is also very important. Together with the improved pedestrian environment, digitisation has helped increase public take-up. Real-time information is distributed to passengers to facilitate their journey planning via mobile apps and display boards at BRT stations (this has also been implemented in numerous other cities such as Guangzhou, Kunming, etc.). Overseas studies[205] have revealed that the provision of such information can increase ridership and reduce both the actual and perceived waiting time of passengers.[206,207]

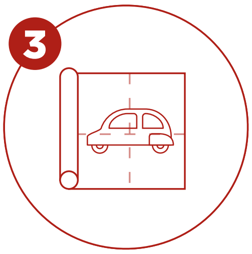
The success of such a large-scale project relies heavily on the collaboration of different stakeholders. Besides Yichang municipality's active involvement in the management of the BRT project and associated works, the Institute for Transportation and Development Policy (ITDP) and other project consultants were also appointed to advise on the enhancement of BRT design and integration with the urban environment.

Financially, being able to secure significant investment was crucial as the construction of BRT is capital intensive – the Yichang project cost more than CNY 2 billion (USD 0.32 billion) in total.[208] As well as funding from a public-private partnership (PPP) made up of the local government and Yichang Urban Construction Investment Holding Group, additional financial support from the Asian Development Bank greatly relieved financial pressure on the local government and expedited the project's implementation.



Scale up remanufacturing and use more recycled materials

Scaling up the remanufacturing of vehicle components and using recycled materials to produce new vehicles has the potential to close material loops and reduce upstream demand for raw materials and energy. Remanufacturing vehicle parts could be particularly promising in combination with leasing or vehicle-as-a-service models as they prolong the use of assets. In these cases, the necessary reverse logistics are easier to manage. As examples like Renault's Choisy-le-Roi remanufacturing plant have shown, remanufactured parts, such as gearboxes, injection pumps, and cylinder heads can be >30% lower in cost while having the same guarantee and quality control as new parts. Indeed, at Renault, the savings achieved by remanufacturing parts compared to producing new ones are as follows: 80% less energy, 88% less water, 92% less chemical input, 70% less waste production.[209] The economic and environmental benefits of remanufacturing are leading OEMs operating in China to invest in new facilities. For example, Volvo China has a remanufacturing plant for its buses and trucks, and companies such as Mercedes and General Motors are expected to set up remanufacturing plants by the end of 2018.[210] If such initiatives are encouraged and scaled up, they could open up opportunities for improving the economics and the environmental impacts of the current mobility production system.



Design vehicles to fit circular mobility system

Circular mobility requires vehicles that fit into a circular system, i.e.. designed with circular economy principles in mind. In practice, this means designing vehicles to be remanufactured, to fit into shared and multi-modal systems, and to be modular and, therefore, easily adapted. Designs should also focus on lightweighting to reduce energy demand.

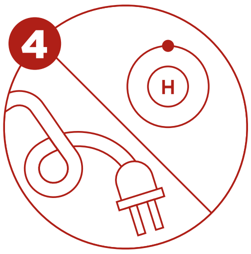
The fact that the average number of passengers per car is under two[211] while most cars are five-seaters is a clear example of the structural waste prevalent in the car fleet. As well as using more materials in their design, bigger and heavier vehicles use significantly more fuel. Vehicles built for purpose, including those meeting the average seat requirement, are a more fuel-efficient and, therefore, less costly mode of transportation.[ii]

Beyond the use of materials, a more integrated approach to the design of vehicles and vehicle-sharing systems could enable a systemic shift in the mobility sector. For example, sharing systems could add flexibility into a designed-for-purpose system, as a car sharer could opt for a bigger car only in situations where more room or seats are required. Taking this idea a step further is another innovative approach to car design – modularity. Using a modular system, cars could easily be adapted from personal car to pick-up or van. For example, Open Motors is a business-to-business (B2B) company that aims to make mobility 100% modular, which means that companies can repair, replace, and adapt components for longer product lifetime, lower the total cost of access (TCA) of the vehicle, and increase its recyclability. It also provides a ready-to-use hardware platform that enables companies to produce complete electric vehicles

ii Based on per passenger calculations.

(EVs) in half the time and at a sixth of the cost of traditional car manufacturing.[212]

Producing purpose-built, remanufacturable, and modular vehicles, as part of an integrated mobility system would offer users more choice, while reducing costs, both financial and environmental.



Scale up zero-emission forms of propulsion

Developing non-polluting, zero-emission forms of vehicle propulsion such as hydrogen and electric is critical to China's commitment to tackling the economic and environmental impacts of its reliance on fossil fuels while meeting the ever-increasing needs of its citizens to travel, particularly to and from work.

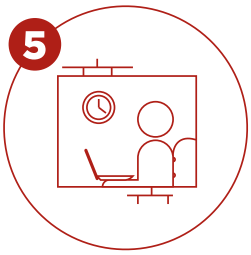
Electric vehicles (EVs) already offer an important alternative to petrol- and diesel-fuelled vehicles. A significant benefit of EVs is that they cost less than internal combustion engines to run since their fuel (electricity) is much cheaper per kilometre than petrol. Also, they have fewer moving parts and, therefore, reduced maintenance requirements, no need for transmission fluid, engine tune-ups or oil changes, and dramatically less brake wear due to regenerative braking systems.[213] Their lower operating costs and projected lower total cost of ownership, as well as potentially significantly lower environmental impacts, mean that EVs are likely to dominate shared mobility schemes.

China has looked to embrace the EV revolution. Several of China's cities implemented heavy restrictions or even a ban on gasoline-fuelled two-wheelers to encourage the adoption of electric alternatives. As a result, China is the largest market for electric two-wheelers and Chinese manufacturers are world leaders.[214] In 2016, the National Development and Reform Commission eased legislation to allow foreign investments in EVs, to facilitate the government target of rolling out five million electric cars on China's roads by 2020. By 2018, Didi had 260,000 EVs registered on its platform, and it expects to expand its fleet of EVs to 1 million by 2020.[215] Beijing is also set to invest CNY 9 billion (USD 1.5 billion) to replace its entire fleet of 70,000 taxis with EVs.[216] Such a shift requires addressing the issue of used EV batteries. In 2015, China's output of lithium-ion automotive batteries was 16.9 GWh, while demand is projected to reach 125 GWh in 2020.[217,218] This presents an innovation opportunity for remanufacturers and recyclers in a new market. More EVs on the roads of China's cities has the potential to become a significant way to reduce the country's carbon emissions. Although to harness the true benefit of this, the shift must go hand-in-hand with a transition to renewables in China's power sector. In 2015, according to the National Bureau of Statistics, more than 73% of electricity was generated from fossil fuels. Over the past decade, dependence on fossil fuels reached a peak of 83.3% of power generated in the two years 2006 and 2007, but has been declining each year since to reach just 73.0% in 2015 – equivalent to a 10% decline in a decade. This is a remarkably swift shift for such a large technical system – particularly one that is growing rapidly – and is the basis for targets that see thermal sources accounting for just 63% by 2020 and less than 50% by 2030.[219] The country's commitment to the Paris Agreement, reinforced by President Xi Jinping's historic speech at the World Economic Forum in Davos in January 2017.[220] To deliver such ambitions, China will need to install 800–1,000 GW of new renewable power capacity by 2030 – an amount equivalent to the capacity of the entire US electricity system.[221]

Fuel-cell technology represents another key opportunity in the mobility sector in China and is expected to receive government subsidies particularly targeting buses and larger cars.[222] Further technological developments could reduce costs and, therefore, aid the scaling up of new hydrogen vehicles with zero-emissions, rapid refuelling possibilities, and sufficient range. A few of China's cities are testing fuel cells in inner- and intra-city buses,[223] with strong support from the Chinese government (a large fuel-cell bus can get as much as CNY one million in subsidies).[224] The subsidy scheme will include passenger vehicles and is expected to promote growth in the sector – the number of hydrogen fuel-cell vehicles in operation nationwide is expected to hit 10,000 in 2019 and 13,000 in 2020.[225]

BOX 7: THE ELECTRIFICATION OF BUS SERVICES

In response to falling security of oil supply and increasing energy demand from road transport, innovation in electric vehicles (EVs) has been actively promoted on a global scale in recent years.[226] While there are various economic incentive schemes to promote electric private passenger cars worldwide, China's cities took it one step further to adopt electric buses on a significant scale. A key example of this initiative can be found in Shenzhen, where a whole fleet of public buses was electrified by 2017.[227] This electrification is one of the key factors in the improvement of air quality in the city, with the number of smoggy days reduced from 115 in 2010 to 35 in 2015, and with air quality improvement goals met in both 2016 and 2017.[228] The average PM2.5 concentration has also reduced by more than 50% between 2010 and 2015,[229] coupled with an overall fall in carbon emissions. Economically, this electrification also offers operational cost savings amounting to approximately 70% in fuel costs.[230] The speed of Shenzhen's transition has been driven by the municipality's various supporting measures. For example, subsidising the operation of electric buses,[231] as well as installation of charging stations to ensure their availability for drivers on their routes.[232] Additionally, having bus manufacturers providing lifetime warranty for the vehicles and batteries helps bus operators to reduce the risks of increased cost due to mechanical breakdowns.[233]



Encourage remote and flexible working

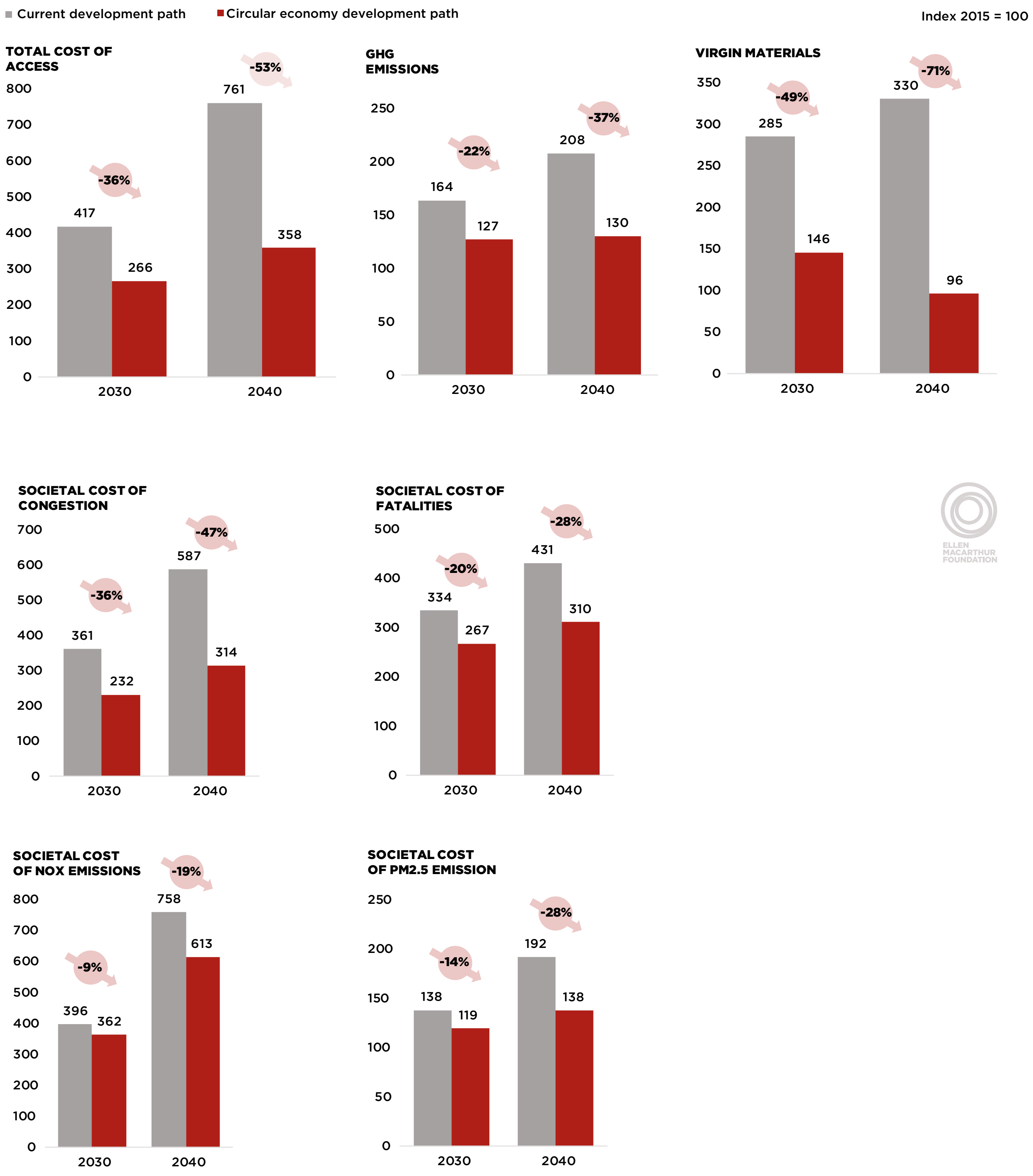
The technology revolution has made the virtual workplace a reality by enabling remote working and virtual meetings. It is likely that a shift to flexible working could reduce the number of passenger kilometres on the roads of China's cities. In Shanghai alone, 60% of the city's 24.5 million residents travel into and out of the city each working day.[234] A reduction in commuter numbers would reduce congestion and improve air quality.

Remote and flexible working is the result of an interaction between technological innovation and organisational change. Shifting individuals to home working relies on the right work arrangements being put in place and the availability of affordable and convenient technologies at work and also in the home or offsite.[235] If such technologies are in place, a worker can choose to work at home or do part-day home working to be able to commute outside rush hours, minimising their time stuck in stationary traffic and therefore reducing air pollution.

The diffusion of new information and communication applications and services could make work even more mobile. Such technologies create virtual offices and foster the implementation of various forms of flexible working, while increasing workers' efficiency.[236] For example, mobile devices, high-speed internet, and cloud storage systems allow more and more work to be done on handheld devices, outside the office or the home.[237]

Importantly, working from home could lead to increased employee performance, greater work satisfaction, and lower attrition rates, as a study has shown.[238]

CIRCULAR MOBILITY: THE BENEFITS FOR CHINA'S CITIES



CALCULATING THE BENEFITS

Current development path

Between 2015 and 2030, the demand for mobility is expected to increase by 400%, driven by population growth, urbanisation, and rising incomes. However, thanks to policies such as the 13th Five Year Plan on developing urban mobility across China's cities during 2016–2020 already introduced by China's government, costs and emissions are expected to improve. The current development path (CDP) also accounts for incremental innovation in technologies and explicit policy targets on emission levels, spelt out by Chinese policymakers, as well as investment packages for the development of urban public transportation systems. However, a non-systemic approach to urban mobility planning would not allow for system-level integration of various modes of transportation. The popularity of privately owned cars would remain high even though sharing would sustain strong growth rates.

Circular economy path

The circular economy path reflects the system-based approach where mobility is highly integrated into urban planning and citizens have convenient access to various modes of transport. The circular mobility system would be multi-modal and shared, employ vehicles designed to fit the system, and be used by a working population that embraces remote and flexible working. Urban residents would be willing to shift towards convenient public transportation, shared mobility or biking. The system would benefit from digital technology to tackle issues such as congestion and road accidents. New digital technologies would also create additional opportunities for virtualising work, which would reduce mobility demand.

Embracing all five circular economy opportunities could reduce the total cost of access (TCA) of mobility by CNY 12.6 trillion (USD 2 trillion) in 2030: an improvement of 36% over the current development path.[iii] 83% of this reduction is in cash-out costs and 17% is in the societal costs of negative impacts such as fine particulate matter (PM2.5) emissions, nitrogen oxide pollutant (NOx) emissions, traffic congestion, and fatalities and serious injuries associated with road accidents. Further implementation of the opportunities could generate benefits of CNY 33.5 trillion (USD 5.4 trillion) in 2040, consisting of 87% in user cost savings and 13% in reduced costs of negative impacts. Furthermore, implementing circular economy opportunities would result in a decrease in consumption of non-renewable resources, including fossil fuels, by 49% in 2030 and 71% in 2040. In the circular economy scenario, tangible opportunities by 2030 stem largely from implementing service-led mobility models. By 2040, additional benefits are derived by a shift towards more remote and flexible working, reducing the overall demand for mobility.

89% of total benefits in 2030 and 80% in 2040 would be supplied by facilitating multi-modal shared mobility.

Taking an integrated and multi-modal approach to digitally-enabled shared mobility would improve the occupancy rate and overall utilisation of the existing vehicle fleet through convenient public transport offerings and vehicle-sharing platforms.

For example, in the circular economy scenario in 2030, 42% of all car kilometres could be made by shared vehicles, rising to 52% in 2040, significantly reducing the total cost of access (TCA) to mobility.[iv]

Following the circular economy path could substantially reduce harmful vehicle emissions compared with the current development path.

iii Total cost of access is made up of cash-out costs and externality costs. Cash-out costs exclude government subsidies and incremental capital expenditure (the added investment needed to move to the circular economy scenario). Externality costs represent the economic costs such as lost earnings and healthcare expenditure associated with, for example, emissions of greenhouse gases and particulates. Details can be found in the Technical Appendix.

iv The decrease of TCA to mobility for urban habitants indicates the amount of money that the users could save thanks to the circular economy opportunities, as well as reduction of costs of externalities for the whole system. Such a reduction would be driven by a number of factors, including in car-kilometres, congestion, CO_2 emissions, and resource consumption, which would not all be achieved on the current development path.

Implementing all five circular economy opportunities could reduce the societal costs associated with emissions of fine particulate matter (PM2.5) by 14%, and of nitrogen oxide pollutants (NOx) by 9% in 2030. This could be further decreased to 28% and 19% in 2040. Furthermore, CO_2 emissions could fall by 22% in 2030 and 37% in 2040. Such reductions would be mostly driven by introducing zero-emission forms of propulsion such as electric, hydrogen or bio-sourced compressed natural gas (CNG). By 2030, 43% of vehicles could be powered by these forms of propulsion, rising to 85% in 2040.

Circular economy opportunities could reduce congestion costs by 36% in 2030 and 47% in 2040. Additionally, the costs of fatalities and serious injuries from road accidents could be reduced by 20% in 2030 and 28% in 2040.

The reduction would mostly be driven by further facilitating multi-modal shared mobility through the development of new technologies such as vehicle automation. By 2040, a network of connected AVs could provide door-to-door and last-mile mobility to city dwellers. In 2040, due to connectivity with other vehicles, AVs could help reduce traffic congestion and the number of road accidents by 15% and 25% respectively. Scaling up the use of remote and flexible workplaces could eliminate more than three trillion kilometres travelled by the Chinese urban population in 2040, contributing to reductions in both accidents and congestion.

NUTRITION: CREATING A REGENERATIVE URBAN FOOD SYSTEM

Within the next decade, the ability of China's agricultural sector to produce an adequate supply of food for the growing and shifting appetites of its urban population, without creating excessive negative environmental impacts, will be tested. Approximately a third of the food that China grows for human consumption is currently lost or wasted. More than 40% of China's arable land has soil that is moderately or severely degraded. Meanwhile, the Chinese urban diet is shifting towards meat making it more resource-intensive. None of these issues has gone unnoticed and the government has signalled its intentions to increase agricultural productivity and reduce food losses so that China can maintain a high degree of food security, this report outlines five circular economy opportunities that, applied in concert, have the potential to make China's nutrition system more efficient and effective in line with national economic, environmental, and societal priorities. They are: Regenerate soil with urban food waste and wastewater; expand business models that promote effective agricultural supply chains; optimise food storage, transport and processing; design out loss and waste of food in the retail system; and reinforce food consumption patterns beneficial to health and the environment.

Capturing these opportunities could create a benefit of CNY 400 billion (USD 64 billion) by 2030 compared to the current development path. Reducing the cost of accessing a healthy diet in this way would have significant environmental and societal gains. For example, greenhouse gas emissions would fall by 6% and PM 2.5 by 85% in 2030. Some of these gains will be found in the agricultural production system, e.g. replacing a share of synthetic fertilisers with compost from urban food waste.[i]

Agriculture and food production continues to be one of China's most important sectors. From approximately 4,000 years ago, when the first dynasty was established, until the mid-nineteenth century, agriculture has served as the main driver of growth for the Chinese economy. While its contribution to GDP dropped by half between 2000 and 2015,[239] the agriculture sector is still sizeable today, constituting around 10% of GDP and 30% of employment, with the entire food and agriculture sector worth an estimated CNY 10.6 trillion (USD 1.7 trillion).[240] China is also a food consumption juggernaut – annual spending of CNY 1.8 trillion (USD 0.3 trillion) makes it is the world's largest consumer of meat, two-thirds of which is pork.[241]

Agricultural productivity has been increasing and further improvements are possible. China's agricultural productivity increased at a steady 11% compounded annual growth rate (CAGR) from 2004 to 2014.[242] McKinsey Global Institute projects a further improvement of 7% compounded annual growth from 2015 to 2030.[243] Much of this improvement is expected to result from operational changes such as mechanisation and the creation of larger and more efficient farms. Currently in China, the main providers

i This analysis – focusing on urban systems – does not account for circular opportunities in agriculture that cannot readily be influenced by urban families and policymakers, such as the sharing of farming equipment and the employment of broad-based regenerative agricultural practices.

are small farms, with an average plot size of 0.65 hectares (compared with 179 hectares in the US).[244] Small farm size limits access to the technology and credit that could help farmers increase productivity and access markets in which they might fetch higher prices for their produce.

The current food system remains wasteful and has negative environmental impacts. About 34% of the food that China's farms produce for human consumption – enough to feed 500 million people – is never eaten.[245] Case studies show that, on average, 5–9% of grain and oil crops, and 20–30% of vegetables and fruits, are either not harvested or lost through spillage, for example.[246] As in many countries, some food losses occur because wholesalers and speculators hoard agricultural goods to drive prices up, which leads farmers to produce an excess the following season. Food culling, which is the practice of discarding products that do not meet certain quality or appearance standards, is a further cause of waste. At the same time, China's food system creates environmental externalities, such as greenhouse gas emissions, high water consumption and pollution, and soil degradation. One reason for this is China's extensive use of agricultural chemicals, which grew from less than eight million tonnes in 1978 to 53 million tonnes in 2013. The application of fertilisers per hectare in China is four times the global average.[247] However, less than 30% of this fertiliser is absorbed by the crops; the remainder evaporates, runs off into surface water or causes local soil pollution.[248] This situation is aggravated by direct manure discharge from China's rapidly growing animal husbandry activities – such discharges now account for over two-thirds of nutrients in the northern rivers and up to 95% of nutrients in the central and southern rivers.[249] Consumption and loss of fertiliser also contribute to greenhouse gas emissions, and, together with pesticide use, make up over 90% of the emissions associated with China's unirrigated crops such as oranges and peaches.[250] Finally, over 40% of China's arable land now has soil that is moderately to heavily degraded – acreage that will need to be either replaced or restored.[251]

China's urban nutrition patterns are shifting. In the past ten years, China has witnessed significant increases in household purchasing power, with a 149% surge in consumption expenditure and a 125% increase in GDP per capita, after adjusting for inflation.[252,253] Over that same period, demand for various foods has risen dramatically on a per capita basis – by 33% for dairy products and 51% for crops.[ii] One of the most pronounced shifts in the Chinese diet is the increased consumption of animal protein. The average Chinese person now eats 63kg of meat per year, six times as much as in 1978, and per capita consumption of meat is predicted to rise by an additional 30kg by 2030,[254] with beef consumption making up 10% of that increase.[255] The Chinese government is said to be aiming to contain this surge in beef consumption because of its potentially adverse effects on human health and the climate.[256]

Overall, China's food system produces some unhealthy outcomes. While China has performed the impressive feat of reducing the incidence of undernourishment significantly, from 23.9% of the population in 1990–92 to 9.3% in 2014–16,[257] obesity now costs the country more than CNY 580 billion (USD 93 billion) per year, equivalent to 1.1% of GDP.[258] Obesity is more prevalent in China's cities than it is in the country as a whole (while it affects 6.9% of the population nationally, in urban areas it is 10.3%). Chinese urban eating habits are rapidly approaching those of developed countries in the West, characterised by excessive calorie consumption and high intake of protein and fat. If left to develop unfettered, the incidence of obesity in China's cities could grow to approximately 25% by 2030.[259]

China's food security is in jeopardy. A major consequence of the problems described above is the likely disruption of the delicate balance between food supply and demand in China within the next ten years. The country has been unable to avoid importing food, because many Chinese field crops cost more than those grown in other countries. Soy offers the most dramatic example, with demand growing at a 9% CAGR from 1964 to 2017,[260] approximately 90% of total

ii Figures from McKinsey Global Insights for the period between 2005 and 2015, except household consumption expenditure growth, which is for the period between 2004 and 2014.

demand is met by imports.[iii],[261] Soya beans grown in gardens and small-scale farms are impractical and inefficient sources for food-grade soya bean traders (likely to be small- to medium-sized businesses), leading Chinese food manufacturers to turn instead to importers.[262] In the face of such trends, the government maintains it is essential to retain a certain level of food security and, to this end, wants to see productivity increased and food loss/waste reduced.

FIGURE 2: DRIVERS AND DIMENSIONS OF FOOD LOSS AND FOOD WASTE IN CHINA

Produce
- Mechanical damage and/or spills during harvesting (e.g. threshing, fruit picking)
- Crop sorting on farm post harvest

Post-harvest
- Spillage and degradation of the farm during
  – handling
  – storage
  – transportation

Processing & packaging
- Spillage and degradation during industrial or domestic processing
  – sorting
  – washing
  – peeling
  – slicing

Distribution & marketing
- Losses experienced during wholesale e.g. supermarkets, retailers etc.

Consumption
- Waste incurred at the household level

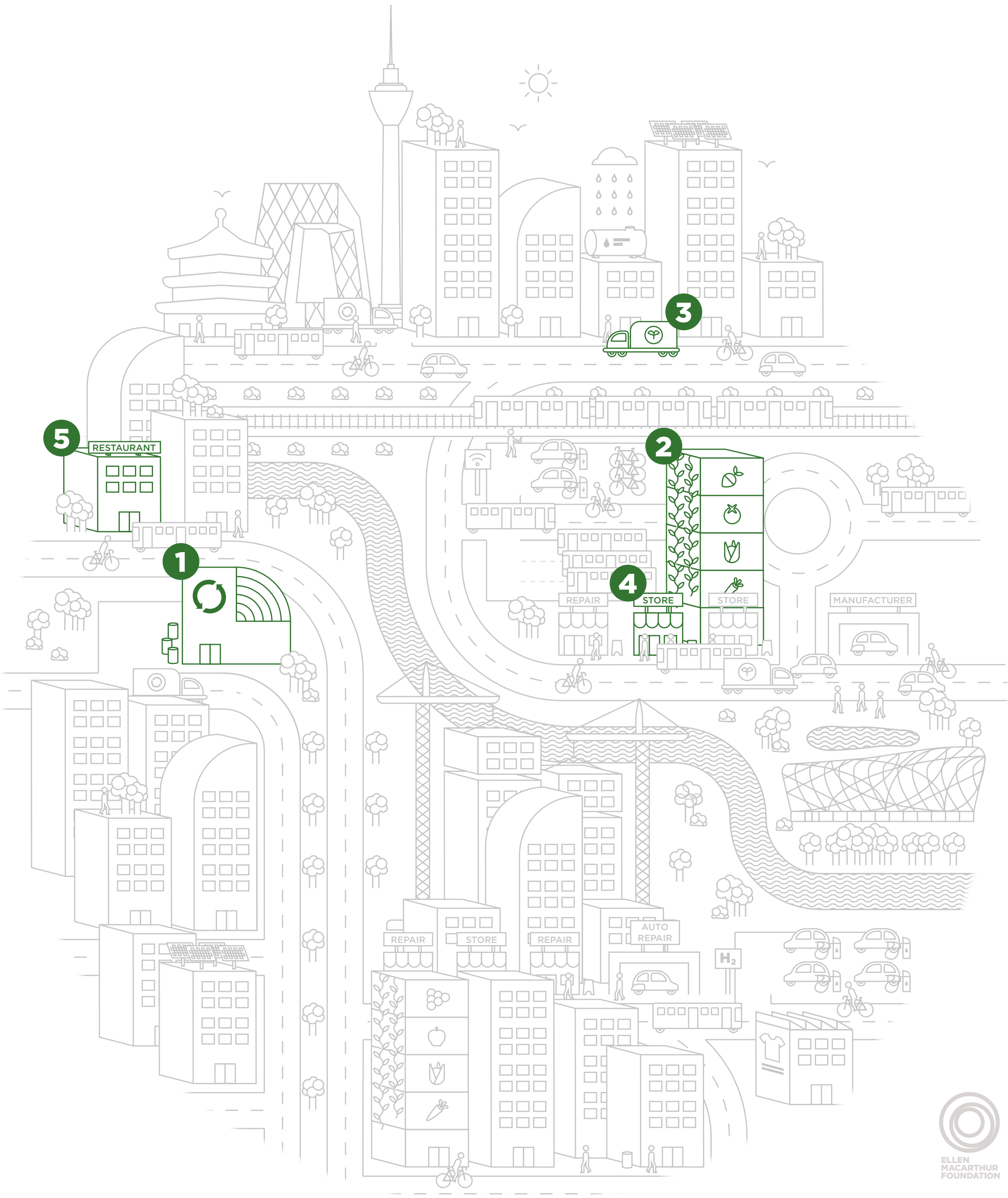
FOOD LOSS AND WASTE IN CHINA, MILLION TONNES 2011

	Produce	Post-harvest	Processing & packaging	Distribution & marketing	Consumption	**TOTAL LOSS,** MILLION TONNES 2011
1 **GRAIN & OILSEED**	42	37	8	10	43	**140**
2 **FRUIT & VEGETABLE**	61	44		36	64	**205**
3 **PROTEIN**	12	8	7	8	12	**46**
TOTAL LOSSES	114	89	15	54	119	**391**

iii Imports of soya beans have been growing at a 12.7% CAGR between 2001 and 2016. ITC, *Trade Map – International Trade Statistics*

VISION FOR A CIRCULAR NUTRITION SYSTEM IN CHINA

China could address these challenges in the coming decades by building a nutrition system that is regenerative, resilient, waste-free, and healthy. This system would build on the technological progress of industrialisation, but retain or even reintroduce elements of the traditional nutrition value chain. The new system would restore land by reconnecting nutrient loops. It would leverage digital solutions and the proximity of food producers to urban households to avoid waste along the value chain. Most importantly, it would supply healthy food.



CIRCULAR ECONOMY OPPORTUNITIES

Regenerate soils with urban food waste and wastewater

The first step in looping nutrients back to agricultural land from cities is to institute source-separated collection and processing of urban organic waste. In 2016, President Xi reinforced the importance of the sorting of food and other types of waste at a meeting of the Office of the Central Leading Group on Financial and Economic Affairs. Stimulating source-separated collection could include incentivising both citizens and government departments, for example, in the form of differentiated collection tariffs that give preferential treatment to source-separated organics. The next step is to increase the quality of the resulting compost to allow access to higher-value markets. Poorly sorted or incompletely matured compost can only be used for zero-value applications, such as landfill cover or low-value applications, such as erosion control in road construction. The last step is to improve operational practices and agricultural technology to increase uptake of such nutrient products. A good example of an innovative optimisation of the value of organic nutrients is Suzhou Jiejing, a successful and profitable organic waste-processing company (see Case Study 2).

DEPLOY COMPOSTABLE PACKAGING TO IMPROVE ORGANIC WASTE RECOVERY

Food and plastic packaging are closely intertwined. Packaging accounts for 26% of the global plastics market, making it the most significant application of plastics in practice, and food packaging represents half of this volume.[263] As such, plastics play an important and growing role in preserving and transporting food. Urbanisation and associated shifts in lifestyle and consumption have seen a rise in China's demand for flexible packaging, particularly in the food and beverage segment, where it is expected to grow at a CAGR of over 8% by 2019.[264]

In targeted contexts and applications, compostable packaging can help capture the nutrient value of the organic waste it once used to protect. Some applications are prone to a high food waste-to-packaging ratio after use, for example, takeaway packaging or food packaging at events, fast food restaurants, and canteens. While the packaging itself contains little in the way of nutrients, the packaged contents usually contain valuable organic nutrients. Compostable packaging can thus act as an important enabler, allowing more unconsumed nutrients to be returned to the soil. The multiple benefits of compostable packaging are shown in the Ellen MacArthur Foundation scoping paper *Urban Biocycles*.[265] For example, coffee capsules are one of the applications that could benefit from increased adoption of industrially compostable plastic packaging. In 2015, the Italian coffee company, Lavazza, unveiled compostable plastic coffee pods, produced from wild thistle and coffee beans, entirely biodegradable and certified for organic composting. If a collection system for food waste in general, or coffee waste specifically, is available, such compostable applications could be relevant in the Chinese context – China's coffee consumption is projected to grow by 18% per year between 2016 and 2019,[266] making it a major coffee-consuming country.[267] Generally, the use of compostable food packaging should always be coupled with the appropriate collection and composting infrastructure to ensure that these packages are effectively composted. In addition, to avoid negative impacts on the economy, public health and the environment, only packaging material that complies with widely accepted standards on compostability should be used.[iv]

iv The role of compostable packaging in a circular economy is described in more detail within the Ellen MacArthur Foundation report *The New Plastics Economy: Rethinking the future of plastics*.

With many of China's cities, such as Guangzhou and Suzhou, launching initiatives aimed at implementing collection, sorting and treatment systems to capture organic waste value, city managers are looking for ways to improve programme performance. One helpful addition to such programmes is the use of compostable bags for collection. In Italy, which has an excellent track record for organic waste management, the city of Milan found compostable bags to be effective in increasing the amount of food waste being collected from households. In 2011, the city introduced compostable plastic bags that were certified suitable for anaerobic digestion or industrial composting in the door-to-door household collection of organic waste and equipped households with a kitchen caddy. This initiative, coupled with other interventions, more than tripled the city's organic waste separation rate from 28kg of food waste in 2011 to 95kg in 2015.[268]

RECOVER NUTRIENTS AND OTHER MATERIALS AND BUILDING BLOCKS FROM SEWAGE SLUDGE

There is already strong policy support in China for investment in sewage treatment infrastructure and technology, including but not limited to the 12th Five Year Plan which features a target of 85% of urban sewage to be treated by 2015. In addition, the 13th Five Year Plan focuses on the upgrade of municipal wastewater treatment plants (WWTPs) and new wastewater treatment capacity, sludge management, wastewater reuse, private sector involvement in utility infrastructure projects, and centralised WWTPs in industrial parks (see Case Study 3). Sewage – commonly seen as a liability – could be valorised, transforming wastewater treatment from a major cost centre into a resource-neutral or even profit-generating 'biorefinery' that creates a variety of useful end products from energy to biopolymers (see Table 1).

CASE STUDY 2: TURNING URBAN ORGANIC WASTE INTO RESOURCES

Suzhou, a city with a population of 10 million, has an exemplary kitchen waste treatment project operated by Jiangsu Clean Environmental Technology Co., whose treatment plant has a capacity of 400 tonnes/day.[269]

The Suzhou municipality plays a crucial role in ensuring the success of this waste treatment project by mandating restaurants send their organic waste to Jiangsu Clean Environmental Technology Co. in exchange for their annually renewed operation certificates. This intervention secures a high quality and quantity of feedstock for the plant.

Suzhou enjoys a strong waste collection capability as a specialised team is responsible for both collection and treatment. By taking a unified approach, the municipality simplified the process and solved the previous challenge of poor front-end collection and sorting management due to lack of incentives. They have formed their own logistics division for the collection and transferral of organic waste, comprising 22,000 bins with digital sensors, 22 specialised vehicles, and 130 dedicated staff.[270]

Many practices of organic waste treatment in China do currently profit from the support of a municipality in the form of benefit. However, striving for financial independence is crucial in the long run, and Jiangsu Clean Environmental Technology Co.'s success in achieving this is an important example. Through partnering with leading universities, its technological innovations have earned 20 patents[271] and the company was able to develop a diversity of useful and marketable outputs. For example, the solid and liquid fractions are separated at the plant. While the liquid fraction is sent for biogas generation, a substantial part of the solid fraction is made into organic fertiliser for use on agricultural soils. Some of the solid fraction is used to breed flies, whose larvae can be sold as high protein feed for 7,500 RMB/tonne, making a significant contribution to the economic sustainability of this business model.

CASE STUDY 3: SEMIZENTRAL RESOURCE RECOVERY CENTRE

In a circular economy, as in nature, there is no such thing as waste – just feedstock and nutrients. Applying this mindset to urban sewage and food waste means shifting from greenhouse gas-emitting landfill and expensive wastewater treatment plants to productive biorefineries that provide a range of useful products and revenue streams (see Table 1).

This is exactly what is happening in the eastern city of Qingdao, where a new approach to urban infrastructure was deployed in 2014 and has been operating successfully ever since. The Semizentral Resource Recovery Centre (RRC) collects wastewater and food waste from a population of 12,500 people and converts the organic matter into electricity,

heat, soil conditioners, and non-potable water. The RRC's catchment area consists of residential districts, hotels, offices, canteens, guest houses, and the village of Shi Yuan.

By 2016, the RRC was able to reuse 100% of the wastewater generated, leading to a 40% reduction in drinking water demand from the municipal supply. This was achieved by using treated and disinfected wastewater for purposes that do not require drinking water quality, such as toilet flushing and landscape irrigation. Reducing potable demand is crucially important for this water-scarce coastal city, which has only one-seventh of the national average of renewable freshwater resources. As well as producing non-potable water, the RRC also generates electricity by converting biogas created through anaerobic digestion (AD). Integrating food waste into the AD plant as a feedstock increases the production of biogas and electricity, contributing to an energy self-sufficient operation. Any surplus electricity produced can be exported to the grid, providing extra revenue. After energy production, the residual digestate is collected by farmers and applied to their crop fields as a soil conditioner.

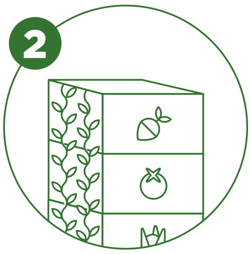
Taken individually, the technologies that make up the RRC are well established. The real innovation has been to bring the sectors together in one integrated operation, so creating a significant synergy effect. Challenges included getting buy-in and approval across several government ministries, as well as building the operator capacity and skills to manage a wide range of technologies (including membrane treatment, sewage sludge AD, thermal electricity generation, and yield management) that are not usually found under one roof.

There are advantages to scaling up such an approach in terms of both optimising capital expenditure and reducing planning costs. However, as the Semizentral model focuses on water reuse on a household scale, certain advantages could be lost if the population becomes too large. For example, there could be additional pipeline costs or heat losses arising from long-distance transportation of grey water, meaning additional energy inputs for biological treatment. For this reason, a population of 100,000 is viewed as optimum, and is a common development size in China's fast-growing suburbs and dormitory towns.

The success of Semizentral and other such plants (e.g. Bioplus and Ecala) in combining wastewater treatment with energy production, high-value conversion of food waste, soil regeneration and a significant reduction in potable water demand could be a model for the future. An integrated approach of this kind could be a paradigm shift, greatly reducing the environmental and economic costs associated with the provision of water, energy, and waste services in China's cities.

TABLE 1: WASTEWATER SHOULD NOT BE WASTED – LIST OF RESOURCES THAT COULD BE EXTRACTED

GROUP	PRODUCTS	USES	TECHNOLOGY MATURITY LEVEL
Water	Potable & non-potable water	Industrial, cooling water, landscaping, agriculture, & aquaculture	High
Energy	Biogas	Heat or electricity generation	High
Treated sludge	Biosolids, biogrout, biochar	Soil conditioning, land reclamation, building materials, & nutrients	High
Nitrogen & phosphorus	Phosphates, detergents, & phosphoric acid	Fertilisers	High
Cellulose	Recycled cellulose (Recyllose™)	Plastics, insulation, cardboard, & construction	Medium-high (number of installations around the world)
Algae	Biodiesel, alginates	Fuels, animal feed, paper industry (alginates), pharmaceuticals, & cosmetics	Low-medium (rotating algae bioreactors – prototypes around US)
Commercial chemicals	Succinic acid, ethyl acetate, methyl acetate, & butyric acid	Platform chemical for many sectors including polymer & bioplastic production	Low
Duckweed	Biomass	Fish food for tilapia	High
Data	Public health data sets	Predicting disease outbreaks, neighbourhood health	Theoretical



Expand business and operational models that promote modern, effective agricultural supply chains

There are a number of opportunities to use modern technology and novel organisational and contractual set-ups to increase effectiveness and efficiency in agricultural supply chains. Digitisation can bring producers and consumers together, for example, through online platforms, and modern agricultural technology can be used to establish highly efficient farms on small areas, enabling more effective peri-urban and urban farming. Models that can contribute meaningfully to regenerative, healthy nutrition systems for China's cities include:

- **Farm-to-consumer (F2C)** direct sourcing models such as JD Fresh, an online food retailer, can reduce transportation distances, thereby better retaining quality and nutrition levels and reducing wastage of foodstuffs and fuel. By creating supplier transparency and proximity for urban families, such models also have the potential to stimulate demand for sustainably grown produce. In recent years, China has also seen an increase in community-supported agriculture (CSA), which provides a close link between consumers and farmers by sharing the risks and benefits of food production. Currently, there are over 800 CSA projects serving more than 100,000 consumers in China, and most of them are located on peri-urban land and cultivated organically.[272]

- **On-demand farming** models, such as Alibaba's Jutudi, and transparent marketplaces, such as Yimutian, are better at predicting demand and thereby reduce over-production. While contract farming can bring its own problems, such as the excessive application of standards around size or aesthetics that can lead to discarding, such farming models could, in tandem with loss avoidance and the development of processing industries, contribute to a more stable revenue stream and employment for the farmer.

- **Peri-urban farming** can successfully cater to the need of urban dwellers for high-quality food and more transparent supply chains, as well as offer farm- and nature-based leisure activities within easy reach of the urban core. Peri-urban and urban farming practices reduce transportation distances. They increase the use of urban organic waste – food waste and nutrient-rich water, for example – and limit water consumption. Tony's Farm, one of China's oldest and largest peri-urban organic farms, cultivates 225 hectares on two sites just outside Shanghai. The farm, which employs about 200 people, has attracted around CNY 250 million (USD 40 million) of investment – from its own funds, government funding, and venture capitalists. It reaches the market through household subscriptions, a supermarket chain, and about 20 restaurants and canteens.[273] In fact, Shanghai has a history of successful peri-urban agriculture and covered more or less its entire vegetable demand from farmland within the municipality up to the 1980s. In 2012, agricultural production within the Shanghai municipality supplied 55% of Shanghai's vegetables and 90% of its green-leaf vegetables.[274]

- **Vertical farming** models cultivate crops – so far mostly leafy vegetables with a high value per kilogram of biomass – indoors and under strictly controlled environmental conditions. The need for pesticides can be completely eliminated and urban farming can use up to 70–90% less water than traditional farming.[275] Due to the stacking of planting surfaces, yields per unit areas can be increased up to ten times compared with conventional agriculture.[276] In terms of nutritional value of hydroponically[v] grown food, the jury is not yet out. While many are critical of production outside a soil that could bring valuable micro-nutrients, there is also some evidence that the nutrient content might be higher. For example, one study found hydroponically grown lettuce to have 229% to 497% higher tocopherol and 93% to 216% higher ascorbic acid content than its soil-grown counterparts.[277] Currently, most vertical farms are designed with artificial lighting to grow the plants. This requires large energy inputs, which is a key driver of the high costs still associated with vertical farming. Developments such as specialised LEDs that emit wavelengths optimised for photosynthesis, as well as further improvements to energy efficiency in lighting technology, could decrease this energy cost.[278] Further improvements in renewable energy generation could also facilitate energy cost reductions and minimise associated carbon emissions. In the absence of immediate solutions to render high-density production systems, such as vertical farms, less costly, other forms of urban farming might be more readily accessible. While the potential of community and rooftop gardens is more limited in terms of volume because of crowded urban spaces, the associated operating costs are potentially far lower. Studies have also shown that using rooftops for hydroponic food production is already economically viable in warm climates, such as South China, providing very locally grown food in an urban area.[279]

These new business models could provide great economic benefits for the farmers. For example, the 580 farmer members of Lvyuantianxing Eco-Farms (LYTX) each receive an annual rent of CNY 22,500/ha (USD 3,600/ha) and an annual bonus, while they can also be hired for farm work or for management of the farm. The annual revenue for LYTX ranges between CNY 30 million and CNY 40 million (USD 4.8 million and 6.4 million). This revenue is generated not only through urban club member fees, but also from selling the fruit and vegetables directly to Walmart and Carrefour through long-term contracts.[280] Such contracts not only allow farmers to be paid ahead of time, but also inform them what to grow so that they can directly cater to the market. This arrangement can reduce food waste at source by preventing unwanted food from being planted in the first place, so reducing the risks of inaccurately predicting market demand.

BOX 8: EMBRACING CIRCULAR OPPORTUNITIES IN AGRICULTURE OUTSIDE CHINA'S CITIES

The nutrition value chain offers further circular economy opportunities outside the urban context.[vi] Some of these, such as resource-efficient farming practices, are well known but need scaling up. Others, such as regenerative agriculture, are anchored in traditional Chinese practices and need to be revived and enhanced using recent technological developments (e.g. robot-supported or data-rich precision farming). There are also opportunities to apply sharing and access models to agriculture that could bring benefits to those tending China's fields and herds.

Adopt regenerative agriculture practices. Regenerative techniques, such as no tillage, cover crop integration, and valorising agricultural waste, have been shown to build soil fertility and improve the functioning of water cycles. On the water side, applying regenerative farming practices results in higher rates of infiltration into the soil and larger retention capacity in the soil, which can reduce both flooding and the need for irrigation. One example is Lvyuantianxing Eco-Farms (LYTX), located in the Daxing district of Beijing. Occupying around 100 hectares and producing Chinese herbs, fruits, and vegetables, the farm is committed to regenerative and organic farming practices. Ducks roam under the fruit trees eating pests and weeds, while their droppings and those of other farm animals are used as manure on the crops, in lieu of chemical fertilisers. No chemical pesticides are used on the farm; a patented herbal recipe is used instead to keep pests at bay.[281]

Apply sharing economy concepts to agriculture. Equipment-sharing models (e.g. in cooperatives) could improve farmers' access to superior technology and

v Hydroponics is a subset of hydroculture, the method of growing plants without soil, using mineral nutrient solutions in a water solvent.

vi These circular economy levers were not part of the modelling as there is very little that urban families, enterprises or policymakers can influence here.

reduce their exposure to debt. Such models also eradicate some of the embedded wastefulness typical in asset-heavy sectors by maximising asset utilisation for these pieces of equipment. Examples across machinery and agricultural inputs include Ravgo and MachineryLink. Nongjibang, Etian, and various agriculture cooperatives are already pursuing sharing schemes for agricultural machinery.

Adopt resource-efficient farming practices. Such practices and technologies are available, and the central government is encouraging their adoption. However, small farmers have limited access to capital, since they cannot use their land as collateral for loans. Improving this access so farmers can invest in agricultural machinery and technology, for example, drip irrigation and precision agriculture – now also offered by Chinese players, such as Hexun and Unistrong – is therefore key. Furthermore, better access to information on weather changes and market price trends, alongside greater knowledge of advanced farming practices, would help small farmers improve resource efficiency. A 2012 experiment conducted by Huang *et al*. shows that appropriate training programmes could enable a reduction of more than 20% in inorganic nitrogen fertiliser use.[282] A further example is the deployment of soil testing to improve fertiliser management. This and other components of the government's aim of zero growth in chemical fertiliser use by 2020 could help improve surface and groundwater quality and reduce soil acidification.

Optimise food storage, transport, and processing

The majority of post-harvest food loss in China stems from poor storage and transportation conditions, and a system of multiple middlemen and agents that results in long transportation times. The scaling up of urban and peri-urban farming models would help to combat these issues by shortening transportation distances from food to customer. In addition, circular nutrition systems could benefit from adopting the following four types of intervention:

Improve storage.[vii] Improper storage causes the greatest food loss in the post-harvest stage,[283] especially for grains, fruit, and vegetables. For example, after being harvested, grains need to be dried for safe storage. However, over 15% is stored under less than ideal circumstances, either because there is not the capacity needed for mechanical drying or because proper silos are not available and the grain is relegated to basic open-air facilities.[284] The NDRC, Ministry of Agriculture, and Ministry of Finance have mandated the elimination of more than 95% of China's open-air grain storage by 2020, and China has reported the addition of 75 million tonnes of grain storage capacity between 2011 and 2015.[285]

Invest in more comprehensive cold chain infrastructure. China's adoption rate for cold chains – an uninterrupted series of temperature-controlled production, storage, and distribution activities – is also low. Cold chain usage for vegetables, meat, and aquatic products stands at just 5%, 15%, and 23% respectively, causing loss rates of 25%, 12%, and 15% respectively.[286] By contrast, developed countries, such as the EU member states and the US, have achieved 100% cold chain usage for meat products and more than 95% for vegetables and fruits. This ensures a loss rate of a mere 1–2% throughout the whole logistics chain.[viii] Investment in upstream and downstream cold chain infrastructure, and promotion of the sharing concept in downstream cold chain storage, could clearly create major benefits. In the last few years, cold chain companies such as Rongqing and Zhengming have been investing heavily in such infrastructure.[287] Shouguang Xinle Agriculture Technology Ltd, located in China's 'vegetable

vii Not included in the quantitative modelling of this report.

viii Spoilage ratio in upstream processing/packaging link, vegetable and fruit example. UN FAO hometown', the city of Shouguang in Shandong province, has created a vegetable and fruit estate that provides integrated production-location services. These services encompass production demonstration, pre-refrigeration warehousing, processing, trade, and temperature-controlled delivery.

Simplify the food distribution chain.[ix] Excessively long transport or storage times result in meaningful nutrient losses. For example, vegetables can lose 15% to 55% of their vitamin C in a week.[288] As China's small farmers often do not have direct access to the market, food typically has to pass through multiple middlemen and travel long distances. It goes from local aggregators to wholesalers, then a retail market such as a wet market, before reaching households. Multiple middlemen not only increase transportation time compared with a direct distribution channel from warehouse to household, but they also increase the number of times a crate or bag is physically handled – and therefore potentially mishandled. Cooperatives that provide farmers with the necessary negotiation power to create linkages further down the value chain, wet markets with better access for individual farmers, and modified retail contracts could do away with one or more of these transaction layers.

Expand processing and packaging infrastructure for key foodstuffs. China's processing industries are still at an early stage in terms of both value added and resource efficiency. Because the processing equipment manufacturing industry is highly fragmented, with over 450,000 small- to medium-sized players, investment in R&D and equipment is lagging.[289] Indeed, it is estimated that over 80% of the agriculture sector's R&D budget is spent on the production stage,[290] whereas processing technology innovation has been neglected. Furthermore, less than half the CNY 8.1 billion (USD 1.3 billion) total import value of food and agriculture equipment goes on processing equipment; the rest is spent on cultivating and harvesting machines.[291]

In a circular nutrition system both farmers and households would benefit from an expanded and upgraded processing infrastructure. An increased processing capacity would result in fewer harvested crops not making it to urban fresh markets because of logistical or commercial reasons, as excess crops would still make it to market in a processed form. Furthermore, technology and facilities upgrades could counter the often significant losses caused by substandard processes and practices. Such processing losses vary from product to product with loss rates reported at ~5% for cereals and ~10% for roots and tubers.[292] A key source of losses is the inefficient use of by-products, such as trimmings and peel. Oranges are an example where raw materials, such as peel, are commonly thrown away, even though orange peel can be recycled and made into Chinese traditional medicine and snacks.[293]

Design out loss and food waste in the retail system

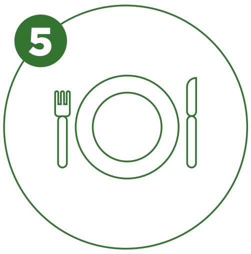
Improve operations and change aesthetic and other quality demands to reduce food loss in retail markets. Losses in wet markets, grocery stores, and supermarkets are mainly the consequence of operational challenges and quality concerns. Most food losses happen because of poor inventory planning. Advanced supply chain management techniques, such as vendor-managed inventory and demand forecasting based on Big Data, are not yet prevalent in China's urban grocery outlets.

Furthermore, quality standards such as freshness and aesthetic standards are often high, due to rising concerns around food security in China. Under food regulations, food must be sold before a date which represents only half of its total shelf life. Take imported milk as an example – it normally takes three months for such milk to be processed, transported, and passed through inspection and quarantine before reaching the supermarket shelf. With a total shelf life of 10 to 12 months, liquid milk can only be on sale for three months and must

ix Not included in the quantitative modelling of this report.

always be rejected and thrown away once it has reached the six-month limit.[294]

Maximise the use of currently unmarketed products. Produce and crops that do not clear the high bar that food retailers typically set in terms of size and aesthetics are usually still perfectly consumable. Getting these and other 'less-desirable' foodstuffs to the market is an important circular intervention. Expanding sales channels for off-grade foods (e.g. from contract farming) and close-to-expiry food, donating to charity, and challenging common notions around quality and aesthetic standards (e.g. the 'ugly food' campaign by Intermarché and others in Europe) are all valid ways of achieving this. In Beijing and other cities, supermarkets have set up special sections for food that is close to its expiry date.



Reinforce food consumption patterns beneficial to health and the environment

Adapt retail and marketing practices that discourage unintended wastefulness. The majority of food waste in China is generated through household consumption. Approximately 85% of food wasted in the home is thrown away during preparation in the fresh, raw stage, mainly due to improper storage, poor planning, and impulse and bulk purchases. These issues can be addressed. Retailers and wet markets could contribute to household waste reduction by dropping promotions based on volume purchases (e.g. 'Buy one, get one free') and limiting stimuli towards impulse buys as part of their sales strategies. Policymakers and retailers could collaborate towards clearer date labelling to avoid the confusion over different labels such as 'sell by', 'best before' and 'use by' dates that causes many customers to throw away food prematurely.[295] A further contribution could come from promoting food from a certified efficient supply chain. Chinese consumers show a growing interest in 'trading up' to better quality products and brands, with more than half indicating such an interest in a recent McKinsey survey.[296] The consumption of high-quality food such as organic vegetables – today relatively low compared with other countries – could be stimulated, in part, by introducing a system, trusted by China's urban citizens, that certifies and grades food quality.[297,298]

Address China's strikingly high wastage of food consumed away from home (FAFH) through education and technology support. Food consumed outside the home in China represents 20% of consumption but 30–40% of total food waste. This is mainly due to China's pervasive 'banquet culture' – the lavish purchasing and eating habits of the new mainstream consumers, which accounts for 25% of all food consumed away from home. Such habits, while deeply engrained, can be modified.

An encouraging start was made by the 'finish your plate' campaign launched in 2013.[x] On average, diners leave 11–17% of their meals uneaten, either because they have purposefully over-ordered or due to large portion sizes. New restaurant concepts could do away with large and inflexible portion sizes by promoting quality over quantity, and encouraging diners to take home leftover food.

Plate waste may account for 75% of all hospitality and food service waste, but it is not the only source of losses. Kitchen losses, due to poor supply chain management, pressure to maintain food supply to cater to extensive menu options, and a lack of staff training and education, can also be tackled. Minimising these losses would require kitchens to deploy technology and best practices to tackle difficulties in forecasting demand and the time constraints

x Although a complete assessment of the impact of the campaign is not yet available, case studies exist that are based on a school campus and company canteen's reduction of food waste after the 'finish your plate' campaign. http://www.xijing.com.cn/info/1108/4290.htm See also http://www.thepaper.cn/newsDetail_forward_1696578. Together with the anti-corruption movement in recent years (which has sought to reduce the lavish meals which have long been part and parcel of Chinese deal making), this seems to have exerted a positive influence on food waste reduction in out-of-home settings.

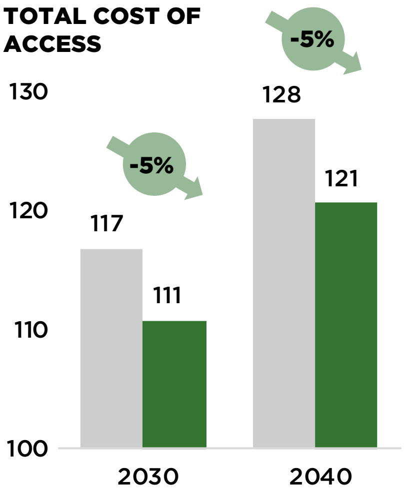
faced by prepared-food subsectors. Winnow Solutions, a UK start-up, has proved this can be done by achieving remarkable results in waste reduction in institutional and restaurant kitchens around the world by providing technology support and analytics to underpin behavioural changes in kitchen staff and management.

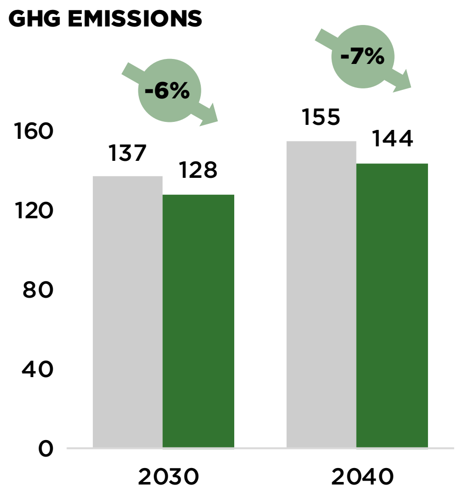
Combat dietary trends such as over-consumption and promote sustainable food concepts. As previously outlined, obesity is already an issue in China and its prevalence is projected to grow significantly. China's National Program for Food and Nutrition (2014–20) recommended that the average calorie intake should be kept at 2,200 to 2,300 kcal per capita, per day by 2020. The programme aims to do this in part by establishing a mechanism for the regular monitoring of nutritional intake levels and diet structure. One example of an intervention with proven impact, and one that is directly related to other circular economy goals, is portion control. Further interventions include reducing the availability of high-calorie food and drink in shops, schools, and workplaces or working with food producers and restaurants to reformulate products to make them healthier, for example, by lowering sugar and fat content. Influencing children's eating habits, through tailored school curricula and by educating parents on nutrition and parental feeding styles, has proved to be particularly effective.[299]

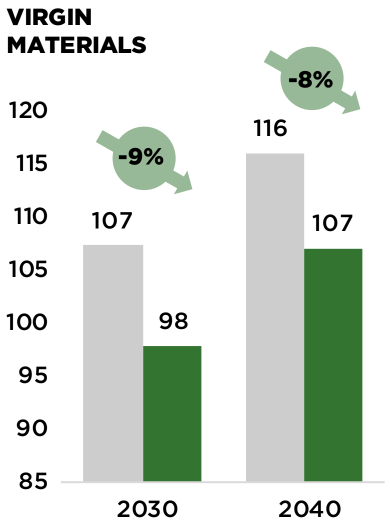
Urban dietary preferences could contribute to regenerative agricultural practices in other ways. Organically grown crops could be an important component in an improved food system. While per capita consumption is low (the size of the market in China is CNY 15.6 billion (USD 2.5 billion)[300] compared to markets in the US and EU of USD 17.5 billion and USD 14 billion respectively), the market is still the third-largest in the world overall and further growth is possible.[301] Over a third of Chinese consumers see organics as a key indicator of safe food, placing it ahead of brand reputation and official or third-party certification as an indicator.[302] Such growth should be profitable, given that Chinese people in the middle- and high-income segments seem willing to pay a significant premium for organically grown food (e.g. quadruple the price for organic asparagus), mostly because it is believed to be safer.[303] So far, growth has come mainly from first- and second-tier cities, but, as the uptake in domestic consumption during the 2008 Beijing Olympics indicated, exposure to organics tends to be a driver of consumer adoption, so growth in smaller cities is to be expected as organics start to penetrate these markets.

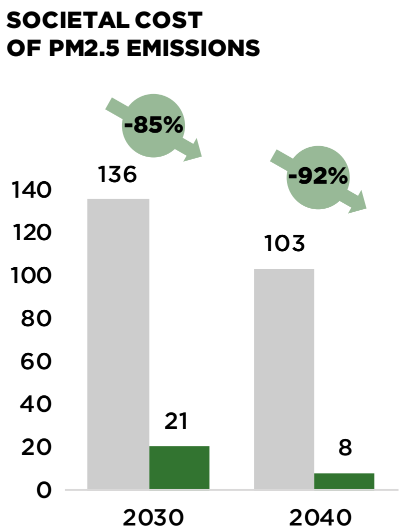
A REGENERATIVE NUTRITION SYSTEM: THE BENEFITS FOR URBAN CHINA

Current development path Circular economy path Index 2015 = 100









CALCULATING THE BENEFITS

Current development path[xi]
Propelled by population growth, urbanisation and rising incomes – and the shifts in consumption and diet that accompany these developments – the cost associated with keeping China's urban population fed in the current development path is projected to rise from CNY 7.8 trillion (USD 1.25 trillion) in 2015, to CNY 10.1 trillion (USD 1.6 trillion) in 2030 (a 30% increase) and CNY 11.5 trillion (USD 1.8 trillion) in 2040 (an almost 50% increase). The main driver of this escalation, in absolute terms, is the increase in cash-out costs, which cover everything in the value chain apart from natural resources. This pathway includes the effects of the full implementation of China's National Program for Food and Nutrition (2014–20), which includes the shifting of subsidies towards certain crops, the drive towards a significant lift in food-processing technology by 2020, and the target to maintain growth rates in food industry value-added of at least of 10% a year;[304] plus the Ministry of Industry and Information Technology (MIIT)'s encouragement of food companies to implement IoT in their supply chain. Together, these policies will increase the performance of the nutrition value chain, but reduce its costs by more than over 40% in the future.

Circular economy path
In the circular economy scenario, there is significant uptake of new business models like vertical farming for fruit and vegetables. Such an uptake will be mostly driven by significant technological development, which also will have a positive impact on preventing food loss during storage, transportation, and processing. Campaigns to prevent food loss and waste in retail, by redirecting currently unused produce, by 2030 will reach the impact level of pilots in the UK and France and, by 2040, will reach best-in-class level (i.e.. reduce all avoidable in-store food loss). The pathway further assumes China follows the UK in reducing supply chain food and packaging waste by nearly 10% and household food waste by 15% over three years. To close nutrient loops, it is assumed China achieves a collection rate of source-separated organic materials of 90% by 2030.

Shifting China's nutrition system towards circular economy models could reduce, and even eliminate, avoidable food waste and losses, while mitigating environmental externalities and improving health outcomes, particularly the prevention of obesity. For urban residents this could mean a reduction in 2030 of CNY 0.4 trillion (USD 64 billion) in the total cost of accessing (TCA)[xii] nutritious food – of which almost one-fifth would be the result of reduced negative externalities. These come in the form of reductions in greenhouse gas emission by 6% and in PM 2.5 by 85% in 2030. The majority of these expected benefits would come from the expansion of urban farms and other advanced business models.

Fully implementing circular economy models in China's nutrition system could reduce the total cost of access (TCA) of food by CNY 0.4 trillion (USD 64 billion), while reducing environmental and societal externalities.

In 2030 the TCA improvement opportunity in a circular economy scenario could be over CNY 0.4 trillion (USD 64 billion) greater than the country might obtain under the current nutrition policy plan. About three-quarters of total circular economy benefits come in the form of reducing the labour, transportation, and processing cash-out costs involved in agricultural products, but costs are also reduced by preventing food waste and loss along the value chain. However, in relative terms, it is externalities and raw materials expenditure that benefit most from moving from the current development path to a circular economy scenario.

A circular nutrition system increases yield at every step of the supply chain.

Applying a circular economy lens to the system in which foodstuffs are produced and

xi In view of our focus on urban levers and impacts, agricultural production is not included in the scope for this sector – this is true for the baseline as well as for future scenarios, where the resource-efficient practices described above were not quantified. The only exceptions are the new agricultural business models, which are particularly relevant for the urban chontext. For all quantified levers, a full value tree, laying out the calculation logic, can be found in the Technical Appendix.

xii Total cost of access (TCA) is made up of cash-out costs and externality costs. Cash-out costs exclude government subsidies and incremental capital expenditure (the added investment needed to move to the circular economy scenario). Externality costs represent the economic costs, such as lost earnings and healthcare expenditure, associated with, for example, emissions of greenhouse gases and particulates. Details can be found in the Technical Appendix.

consumed brings a host of environmental and societal benefits all along the value chain. The most powerful of these drivers might well be that any downstream optimisation – in effect reducing demand – also reduces production and its associated costs. Applying circular economy measures could eliminate some CNY 110 billion (USD 17.6 billion) in spending on primary resources, including water, pesticides, agricultural land, synthetic fertilisers, and energy. The reduction of primary resources comes mainly from eliminating food waste and loss along the value chain, which implies that the current level of food supply is unnecessarily high.

Environmental benefits are generated all along the circular value chain, but unique opportunities exist through displaced agricultural supply and superior waste treatment.

Compared to the current development path, greenhouse gas emissions associated with the nutrition sector could be brought down by around 120 million tonnes of CO_2e, most notably through the elimination of methane released from food waste in landfill.

The need for synthetic fertiliser would be reduced by making sure a higher proportion of agricultural output actually makes it into the hands of end-users, and by using food waste as a soil improver in a regenerative agricultural system. In addition, circular economy approaches would also have a positive impact on the water balance due to a reduction in the volume of water needed for agriculture through the avoidance of volume losses in the post-harvest value chain. Moreover, the use of compost as a soil supplement has proven beneficial effects on soil water retention and so further reduces the need for irrigation.[xiii]

Furthermore, technological improvements in municipal solid waste and sewage treatments could reduce dust, in the form of PM2.5 emissions, by up to 0.2 million tonnes compared to the current development path, amounting to an externality reduction of approximately CNY 61 billion (USD 9.8 billion).

While still fraught with challenges, urban farming and other modern business models could have the biggest impact in a circular urban food system.

Infrastructure interventions are important in a sector where low access to capital should not prevent China's cities, and those catering to their needs, from getting more value out of the system. In the lead up to 2030, approximately 40% of the circular economy potential for the nutrition sector could be derived from new business models. While the pathway towards an increased market penetration by farm-to-consumer (F2C) sourcing models and on-demand farming is fairly straightforward, the case for urban vertical farming in the fruit and vegetable sector requires further technological improvements to fully capture the substantial benefits of increased freshness, reduced pollution, and combatting urban heat islands.[xiv,305]

Changing demand will produce additional benefits in the long term.

By 2040, China can expect to see further improvements in economic, societal, and environmental outcomes in its nutrition system as behavioural changes, such as those addressing waste in households and food service settings, take hold across the population. This creates a unique opportunity for entrepreneurs and innovators to support the behavioural shifts with technology and data-driven solutions – and, in so doing, accelerate and potentially scale the possible impact of a particular opportunity. However, commercial offerings that bring about behavioural change might need some time to be developed, particularly if they look to change longstanding traditions.

A circular nutrition system could also help reduce obesity by fostering healthier lifestyles.

China's fast-rising obesity levels could result in additional healthcare expenses of over half a trillion CNY (USD 80 billion) – a direct externality cost. However, if policies, products, and services were developed to facilitate the shift in eating habits that are driving this trend, and to keep calorie consumption at current levels, then some CNY 343 billion (USD 55 billion) in externality costs could be eliminated.

xiii Not quantified here

xiv The urban heat island effect occurs because the dense dark surfaces, such as bitumen on roads and building materials used in cities, accumulate and store heat during the day and then release it at night.

TEXTILES: MAXIMISING THE UTILISATION AND VALUE OF FABRICS

China is a global leader in the production and export of textiles. The textile industry is currently undergoing major restructuring and transformation, while China's rapid economic growth and urbanisation, coupled with a growing middle class, have already tripled the domestic demand for textiles and will grow threefold yet again over the next decade. Urban citizens are accelerating the shift towards fast fashion,[i,306] while more affluent citizens are increasing the demand for quality and branded luxury goods. Such trends are, however, negatively impacting water reserves, water and air quality, and public health. This unprecedented growth, combined with the traditional, linear 'take-make-dispose' approach to production and consumption, could be mitigated by embedding circular principles within the industry. In a circular textile industry, clothes would be designed and manufactured to last, they would be tailored for the individual's needs, and new business models would be put in place to circulate garments and textiles for several use cycles. Key opportunities that can be captured by the Chinese textile market and manufacturing industry have been identified: pursuing business models that increase utilisation of durable textiles; scaling up recycling; and introducing resource efficiency measures. The implementation of such circular practices in the textile industry could bring about total cost of access (TCA) benefits for China's cities of CNY 0.5 trillion (USD 80 billion) by 2030 and CNY 1.2 trillion (USD 0.2 trillion) by 2040, when compared with the current development path. Taking a full system approach to the textile industry, by ensuring that it is not only restorative but also regenerative by design, would provide additional benefits.

The world's largest textiles industry is undergoing structural changes that could affect the international textile market. China is a global leader in the textiles and garment industry, accounting for 55% of worldwide textiles production in 2014.[307] A significant proportion of its output is comprised of synthetic fibres, of which China generated 44 million tonnes in 2014 – 70% of the world total.[308] Not only is China the world's largest fibre producer,[ii,309] but it is also the world's largest textiles exporter,[iii,310] and the largest textiles machinery manufacturer.[311] China is involved in every activity in the value chain – producing raw materials, natural and man-made fibres, fabrics, and finished products. In 2015, the textile industry accounted for 7% of China's GDP and 7.7% of its exports by value.[312,313]

However, the textile industry in China has recently experienced slower growth. From 2011 to 2015, the average annual growth rate of industrial value added was 8.5%, a notable drop from the 10.3% growth seen between 2009 and 2010.[314,315] Regarding future trends, the 13th Textile Industry Five Year Plan envisages an annual growth rate of 6–7% in fibre production between 2016 and 2020.[316] Nevertheless, the industry is still growing strongly and China is determined to remain the leading textiles player.[317]

To counteract the rising wages and production costs that are hurting its exports, China has started to take measures to relocate some textiles manufacturing plants from the east of the country to western and central regions. Furthermore, the textiles industry has been transitioning from a

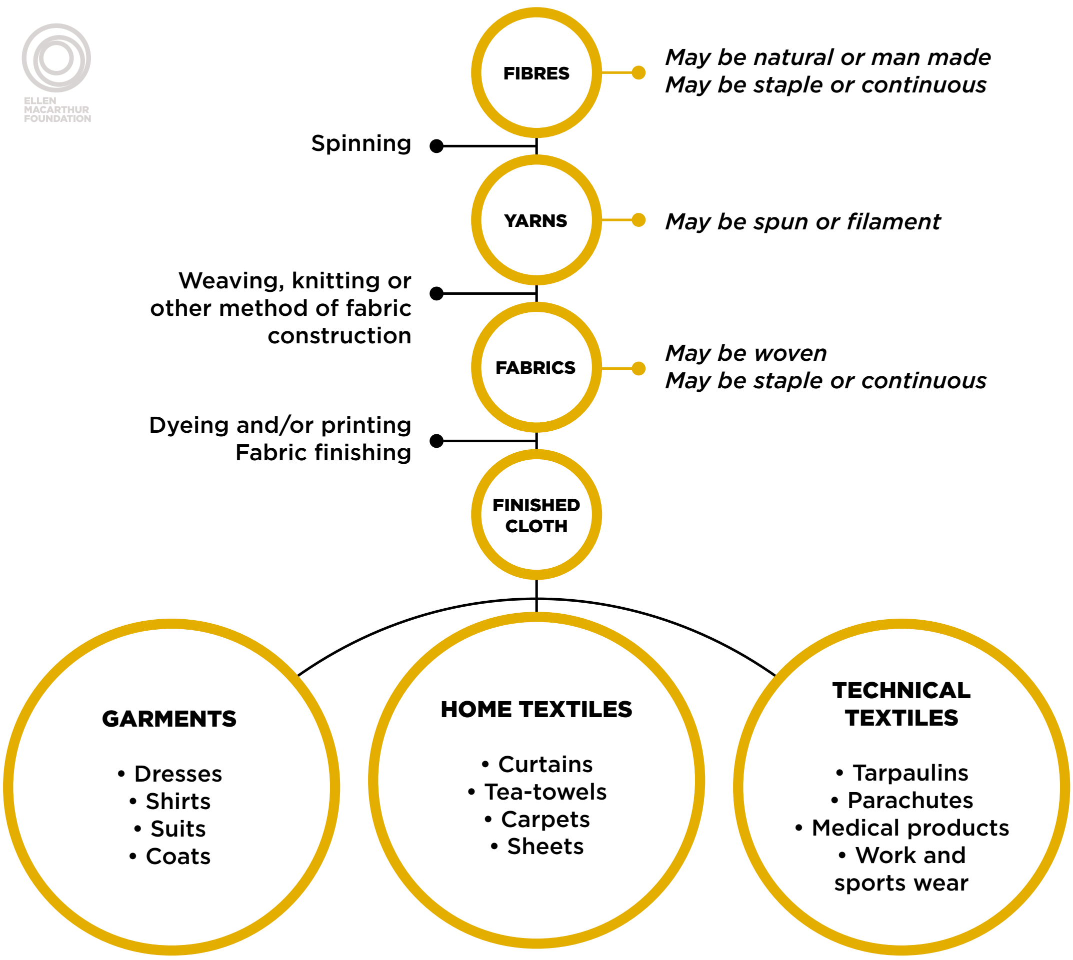
i Fast fashion refers to fashion focused on exceptionally shortened lead times as a means of providing fashionable merchandise to citizens as the trends emerge.

ii Fibre production exceeded 50 million tonnes in 2014.

iii In 2015 China's market share in world textile and apparel exports was 37.4% and 39.3% respectively.

low-value-added to a higher-value-added and technology-intensive model.[318] This is reflected in changes in the production ratio between garments, home textiles, and technical textiles. Between 2010 and 2014, the share of garments decreased by 4.2% and home textiles by 0.4%, whereas the share of technical textiles increased by 4.6%.[319] By 2020, the 13th Textile Industry Five Year Plan expects this increase in technical textiles production to continue with the production make-up to become 40% garments, 33% technical textiles, and 27% home textiles.[320] In China, the technical textile industry has already become a main driving force in the textile industry, with steady growth in the mobility, medical, and built environment sectors.[321,322] See Figure 3 for an illustration of the key stages of textile manufacturing.

FIGURE 3: ILLUSTRATES THE DIFFERENT STEPS INVOLVED DURING THE PRODUCTION OF GARMENTS, HOME AND TECHNICAL TEXTILES[323]



Rapid economic growth is fuelling the expanding domestic demand for garments and home textiles, driving fast fashion and e-commerce trends. Not only as a producer, but also increasingly as a market for fashion products, China is an international behemoth. Already the third largest textile importer, it is projected that, by 2025, China's garment market will be the biggest in the world with a value of CNY 3.4 trillion (USD 0.5 trillion).[324] China's fashion demand, which tripled in size in the past decade, is expected to triple again in the next decade.[325,326] Euromonitor expects that, during the same period, China's garment sales will increase to CNY 2.1 trillion (USD 333 billion), surpassing the US at CNY 1.7 trillion (USD 267 billion).[327] This expenditure is being driven by China's steady rise in average disposable income. By 2022, 75% of China's urban citizens will be middle class, with annual household disposable incomes ranging between CNY 60,000 (USD

9,631) and CNY 229,000 (USD 36,758).[328] Currently, Chinese citizens spend on average almost three quarters less on garments than Americans.[iv,329] However, further growth in semi-necessities (e.g. garments, healthcare, and household products) and discretionary spending (e.g. travel, leisure, and fashionable clothing) is expected by 2020.[330,331]

This increase in disposable income is accelerating the shift towards fast fashion – more disposable and seasonal garments that reflect short-lived fashion trends. This shift has seen China's clothing sales rise above the global average of 5kg per person to around 6.5kg[332] and it is predicted that, by 2030, this may even rise to 11–16kg per person, bringing China in line with North America.[333] China's domestic brands have a dominant position in the garment market and their prevalence in the mid- and low-end sectors makes them well placed to benefit from this rapid growth. Fast-fashion business in China is no longer limited to physical stores, as new technologies have revolutionised the way in which brands and consumers interact. As mentioned in the first chapter of this report, China is already a global leader in e-commerce, with its market of approximately CNY 4.2 trillion (USD 680 billion) in 2015 nearly 80% bigger than that of the US.[334,335] One of the online categories with the highest adoption rates is garments, with an online shopping adoption rate of almost 60%.[336] Currently, Tier 3 cities (and below)[337] are outspending higher tier cities online, [v,338] largely due to citizens in these cities not having ready access to certain goods or stores.[339]

By contrast, Chinese citizens with higher disposable incomes are increasing the demand for more branded luxury goods. They have now formed the world's largest market for luxury consumption, with the sector being dominated by international brands.[340] However, while a few years ago the focus may have been on brands and logos, preferences are shifting towards more value-added products, 'green' products, personalisation, innovation, better quality and services.[341] In higher tier cities, despite the prevalence of e-commerce, the main distribution channel is still shopping malls and physical stores.[342,343]

The growing demand for textiles is having a detrimental effect on water reserves, water and air quality, and public health. One major result of this growth in production and fast-fashion trends is textile waste amounting to 20–26 million tonnes from industry and households annually. [344,345] **China's waste-processing capacity has been unable to cope with overall waste generation, and many landfills in large cities are running out of space.**[346] **In response, the government is now stimulating measures to address the textiles waste challenge, such as recycling.**[347,348]

Furthermore, the textile industry places great pressure on the local environment and natural resources, such as water. For example, China is already facing severe water scarcity with a per capita availability only one quarter of the global average.[349] The textiles industry has now become the country's third largest water consumer, using approximately three trillion litres each year, three to four times more per product than other countries. [vi,350,351] Textiles dyeing and other treatment processes causes 17–20% of industrial water pollution.[352,353] In fact, 72 different toxic chemicals found in polluted waters come solely from textile dyeing, of which 30 cannot be removed through wastewater treatment.[354] When such chemicals are present in finished fabric, they may directly impact human health.[355] The heavy use of chemicals has led to the textiles and garment industry being ranked the second-largest contributor to wastewater chemical oxygen demand (COD) [vii,356] pollutants in China.[357,358]

iv Currently, the average expenditure in China on apparel is USD 240, whereas in the US it is USD 815 per year.

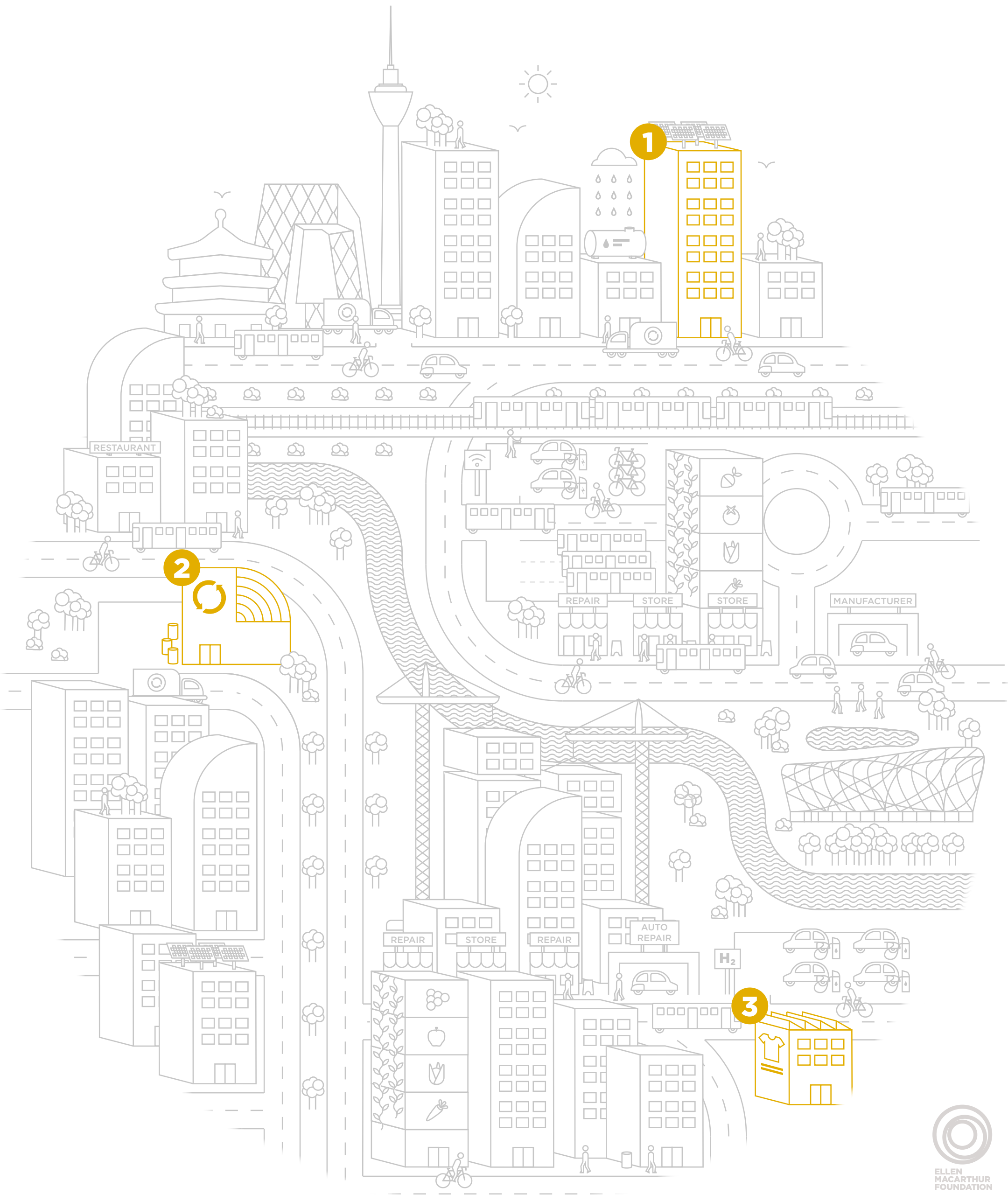
v Lower tier cities currently have 74 million more online shoppers than higher tier cities.

vi The printing and dyeing process is the most energy-intensive process consuming 85% of the water, 80% of the energy, and 65% of the chemicals.

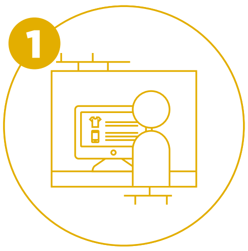
vii Chemical oxygen demand (COD) is an indicator of total organic chemical load. COD is highly damaging to aquatic ecosystems, since it takes dissolved oxygen out of the water column and thereby smothers fish and other aquatic life. COD is the pollutant most commonly causing fish mortality in rivers, lakes, and streams.

VISION OF A CIRCULAR TEXTILES SYSTEM IN CHINA'S CITIES

The future of the textiles industry in China's cities could be one driven by the creation, retention, and reuse of value, while still fulfilling the clothing needs of the Chinese population. The circulation of textile materials for several users through access-over-ownership business models is key to maximising textile utilisation, minimising wastage, and decreasing the pressure on the environment and resources. In a circular economy, clothes would be designed, manufactured, and maintained to last, while preserving the embodied value in fibres. Limited loss in primary resources would be stimulated through the scaling up of recycling initiatives, while also increasing resource efficiencies and minimising pollution throughout the value chain.



CIRCULAR ECONOMY OPPORTUNITIES



Pursue business models that increase utilisation of durable textiles

Textiles that have been designed for quality and can withstand multiple and prolonged use can be circulated in repeated use cycles. Business models such as sharing, renting, and leasing provide customers with a service offering access to products rather than ownership. In doing so, the average number of times textiles are used or worn is increased, customers gain more convenient and affordable access to textile products, and businesses benefit from greater customer loyalty and more consistent revenue streams. Design-for-durability enables these business models and offers a strong business case by enabling extended use of the fabric. If applied to the textile industry, the concept moves away from the current linear ownership model in which clothes are built for obsolescence.

Increasing the utilisation of textiles requires the set-up of reverse logistic systems that allow for fast delivery and re-collection, online shopping sites to provide more convenient and affordable access to clothing, and services to maximise customer satisfaction. The benefits include not only cost savings in fibre production, but also during the manufacturing process and in avoiding externalities.

EXAMPLES OF OPPORTUNITIES FOR THE GARMENT MARKET IN CHINA

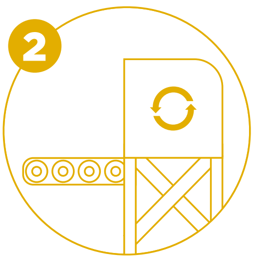
China has become the world's largest sharing economy, with companies such as Didi Chuxing (car-sharing) leading the way.[359] However, this interest in sharing has not yet impacted the garment market as strongly, possibly due to user concerns regarding hygiene and product quality. Nevertheless, a few promising garment reuse models are starting to gain traction in China, particularly for trendy and luxury items. Companies such as Ms Paris and Liangyihui have set up business models based on the online renting and trading of second-hand luxury items.[360,361] Others, such as YCloset,[362,363] have even set up clothing subscription services whereby consumers pay a monthly fee to gain access to trendy clothing, which they can rent and swap at any time. YCloset, which raised CNY 312 million (USD 50 million) in 2017,[364] offers access to mid-range and high-end clothing for a monthly subscription fee of CNY 499 (USD 80).[365,366] The company has observed that trendy durable clothes (e.g. those that are wash resistant) could be rented to up to 40 different people, as opposed to only three to four for lower-quality products. Such companies clearly demonstrate the vibrant future potential of the product-as-a-service approach to clothing in China. In the future, such business models could become especially relevant in lower-tier cities where there is a rise in the middle class, more online shoppers, and where physical retail stores have not yet fully been established.[367]

Furthermore, clothing known as dead stock,[viii] accumulated mainly due to overproduction, could also offer business opportunities for brands.[368] Though few studies have analysed this accurately, Circle Economy suggests that around 10–30% of garments produced are never sold[369] and often destroyed to avoid flooding the market. However, there is an opportunity to renew and resell them alongside new clothing. It would allow brands to take control of secondary markets. Similar opportunities are also present for quality clothing disposed of by urban citizens, and currently often donated or resold abroad.

viii Dead stock refers to items for which there are no sales during a complete 12-month period. Dead stock occupies space in warehouses for a longer period of time and increases the inventory cost. Dead stock is due to overproduction of products that customers no longer want.

EXAMPLES OF OPPORTUNITIES FOR THE HOME AND TECHNICAL TEXTILE MARKET IN CHINA

Home and technical textiles[ix,x] are not widely reused around the world, including in China. However, with the Chinese technical textile market rapidly developing, and reutilisation opportunities left untapped, there is great potential. Service business models which allow renting or leasing of product can be attractive in B2B markets. Dutch carpet manufacturer Desso, for example,has made a business of leasing recyclable carpet tiles, which can be easily recovered and reintroduced into the production cycle after use, offering services that include installation, cleaning, maintenance, and removal.[370] Businesses using technical textiles, which are inherently of high quality, such as high-performance fibres, have similar opportunities. Making use of their traits, such as durability, high strength, and high temperature resistance, in leasing or renting business models, where quality and ability to last are central, could present an untapped opportunity. For example, MEWA is a service-based company that rents out workwear and protective clothing, for which it provides pick-up, quality control, delivery, and replacement services.[371] For companies such as Desso and MEWA, access-over-ownership business models reduce the need for virgin materials which helps them save costs and diminish negative environmental impacts.



Scale up recycling

Scaling up the recycling of textiles presents an important opportunity to keep the value of these materials in the economy for longer. Two recycling opportunities are presented below – mechanical and chemical recycling. To enable the scaling up of textile recycling, it is essential that textile design and recycling technologies are aligned. In addition, innovation in sorting and recycling technologies would be needed. These would enable increased recycling rates and output quality. Increasing demand for recycled materials would contribute to speeding up the uptake of recycled materials while also improving economies of scale (see the section 'Considerations for the textile industry in capturing these benefits').

MECHANICAL RECYCLING

Mechanical recycling involves the cutting and re-sewing (fabric recycling), unravelling (yarn recycling), shredding and reprocessing (fibre recycling), or melting and re-spinning (polymer recycling) of discarded textiles. Processes such as fibre and polymer recycling can provide a substitute for virgin fibres. However, the fibre recycling process shortens the length of the fibres, which means that they need to be blended with virgin fibres or recycled polyester fibres to reach certain quality standards.[372,373] Nevertheless, many companies are innovating in this area. For example, Mud Jeans is now able to use 40% recycled cotton in 100% cotton jeans, which offers great promise for upscaling the use of recycled fibres.[374] For polymers, several recycling rounds at the same value level are possible though there is a cumulative quality loss. Fabric recycling on the other hand often leads to downcycling, producing lower grade single-use products such as wipes. Fibre recycling also often leads to downcycling. Though it is relatively widespread, the shredding process reduces the quality of fibres, and the output materials are often used for lower-value applications such as insulation and fillings.[375,376]

In China, recycling and collection infrastructure are still in their infancy. According to the China Association of Circular Economy (CACE), around 10–15% of discarded textiles are collected for reutilisation.[377,378] Of that share, around 40–50% gets mechanically recycled, while the remainder is donated or resold abroad as second-hand. However, with 20–26 million tonnes of wasted textiles being generated annually, there is enormous recycling potential for China, preventing

ix Home textiles include products such as carpets, mattresses, and linen.

x Technical textiles include products such as high-performance fibres for the medical, transport, and construction industries.

the loss of valuable materials. Germany has already shown that collection rates of up to 74% can be achieved, from which a third is sent for recycling.[379] Currently in China, pilot efforts have mainly focused on collecting and recycling garments rather than home and technical textiles.

BOX 9: COLLECTING FOR REUSE AND RECYCLING

For any form of recycling to take effect, a collection or take-back logistic system is essential for the recovery of discarded textiles from citizens. In China, a number of businesses have begun to tap into this opportunity. For example, Lydai and Feimayi have set up an online platform where citizens can indicate when their to-be-discarded textiles can be picked up for reutilisation.[380],[381] Companies like H&M are offering their customers a discount for every bag of returned clothes.[382]

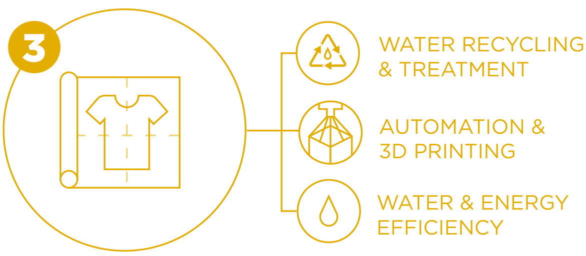
The Chinese government has recently emphasised the importance of establishing collection and recycling systems in its policy document, Circular Development Leadership Action Plan.[383,384] Furthermore, city pilot projects supported by the government, such as that led by Shanghai Yuanyuan, have put infrastructure in place to facilitate citizens separately discarding their textile items. By collaborating with local schools, government institutions, neighbourhoods, and charitable organisations, Shanghai Yuanyuan managed to set up 2,000 bins to collect used textiles all over the city. The collected textiles are sent for donation to 'Hope Project' schools within China (3–4%), resold abroad (10–12%) or mechanically recycled (84–87%).[385,386] Of those textiles recycled with industry partners Dingyuan and Huading Textiles Technology in Hangzhou, 33% is turned back into yarn to make uniforms, while the rest is downcycled for lower-value applications.

CHEMICAL RECYCLING

Chemical recycling is referred to using two different levels of value preservation, namely depolymerisation and polymer recycling. The process of depolymerisation and repolymerisation of plastic-based materials is already employed today. The process involves changing the feedstock material by breaking down pre- or post-consumer fibres back into their basic chemical components – monomers. This process is theoretically able to produce endlessly recyclable fibres by using pure sources or cleaning the recyclate of contaminants.

China already has a plant, Zhejiang Jiaren New Materials Co., that uses the depolymerisation and repolymerisation process. A joint venture with the Japanese company Teijin, whose ECO CIRCLE™ technology enables the production of high-quality fibres, it is a rare example of such technology being used for the recycling of waste textiles into virgin quality fibres. Zhejiang Jiaren New Materials has the capacity to turn 40,000 tonnes of discarded textiles a year into polyester fibres and chips, a rate expected to increase to one million tonnes by 2021.[387]

In contrast, polymer recycling involves the dissolution of cellulose-based textiles or the melting of plastic-based textiles. Fibres are brought to a polymer level, destroying them but keeping the chemical structure of the material intact. There is, however, cumulative quality loss, meaning only a few rounds of recycling are possible before the polymers are too damaged for further looping at the same value-level. Companies are currently testing the viability of such recycling at scale. For example, nylon producer, Aquafil, has managed to produce recycled nylon at a price competitive with virgin nylon.[388] However, the economics of recycled polyester are not yet favourable. Still, the process is gaining interest globally because of its potential to offer virgin-equivalent 'fibre-to-fibre' recycling. Overall, the Chinese chemical textile association is aiming to increase the production of synthetic fibres from discarded textiles.[389]



Introduce resource efficiency measures

Resource efficiency measures help limit the waste of materials, the use of hazardous chemicals, and the consumption of water and energy across the textiles value chain. They reduce costs of production as well as costs related to human health and the environment.

RESOURCE EFFICIENCY IN THE SUPPLY CHAIN

Automation and 3D printing

Automation and 3D printing are technologies that can play an essential role in improving quality, efficiency, and cost competitiveness of manufacturing processes.[390] Utilising such technologies to design efficient material production systems could increase production yield significantly. Currently, around 35% of textiles end up as waste in the supply chain, from which 10–15% is left as cutting waste on the floor.[391,392] However, trends such as the rise in automation, robotics, and advanced machinery are already gaining traction in China. Such technology could increase productivity and reduce fibre wastage. For instance, a study has shown that computer-based systems could optimise yield, bringing a 5% improvement in resource productivity.[393] The benefits for labour productivity could be of an altogether different order of magnitude. One textile mill owner estimated the potential of adopting robotics to have the ability to generate CNY 1 billion (USD 161 million) in sales in one year with only 200–300 workers, increasing productivity per worker by 20 times.[394] Furthermore, though 3D printing is in its early stages, it could change the landscape of manufacturing. Not only does it offer greater personalisation of textiles, but they can be manufactured in hours instead of weeks, with almost no production waste.[395,396]

Efficient water and energy management

The use of water and energy can be minimised along the value chain. The Chinese government has already implemented a number of initiatives to encourage and enforce factory owners to take action. For example, the 13th Five Year Plan states that the textile industry should decrease their annual water and energy consumption per unit of industrial value by 20% and 18% respectively.[397] According to the Water Ten Plan, factories in the printing and dyeing sector that did not comply with national pollution standards by 2016 would be shut down.[398] This threatened nine out of ten textile factories.[399] Those located in water-scarce areas are even required to fully reuse their water.[400] It was also expected that by 2017 the industry should adopt technological upgrades and introduce facilities for the monitoring of pollution discharges. The government has already invested about CNY 15 billion (USD 2.4 billion) in technological-upgrade projects in Zhejiang province, China's largest textile hub.[401]

To help address circular solutions for the industry, Natural Resources Defence Council (NRDC) and Solidaridad (an international network organisation promoting sustainable energy and food production) have both launched pilot programmes at a wide range of mills in the dyeing and finishing sector to identify a business case for resource saving (see Case Study 4). The key areas of the programme include resource efficiency, waste, emissions to water and air, chemical management, workplace health and safety, and social awareness.[402] The largest saving potential achieved by a dyeing and printing mill was a 42% reduction in water consumption,[403] and a 22% reduction in energy consumption.[404] For energy, the largest and most cost-effective reductions came from improving steam systems (including steam traps) and the recovery of heat from exhaust gas, water, and oil.[405] Such pilots have also shown that minimising environmental impact can go hand-in-hand with economic benefits. For example, an NRDC pilot mill managed to obtain an economic return of CNY 22.8 million (USD 3.7 million) in the first year after having implemented projects that increased motor and lighting efficiency, process water reuse, and heat recovery from exhaust gas.[406] The payback period was only 13 months. In fact, 70% of the Solidaridad pilot mills improvement measures only required an investment of CNY 50,000 (USD 8,000) with many having a payback period of less than two years.[407] Solidaridad emphasised that the largest category of improvement opportunities is in better operational management.

Water recycling and treatment

Water recycling enables process water, where possible, to be reclaimed and reused within the factory, reducing freshwater consumption and wastewater discharge. In China, a number of companies and organisations are testing the benefit of reusing water in the textile industry. Crystal Group and Levi Strauss have managed to obtain a 60–65% water recycling rate, with the water being reused in production, land irrigation, and cleaning.[408] NRDC pilots demonstrated that from the various water efficiency measures tested, the reuse of water and grey water yielded the largest and most cost-effective reductions.[409]

Regarding the treatment of wastewater

effluent discharged by the textile industry, pollution parameters are employed to measure and control water quality. Examples of key wastewater effluent discharge parameters of the textile industry include chemical oxygen demand (COD), biological oxygen demand (BOD), suspended solids (SS), nitrogen (N), and phosphorus (P). Ensuring that discharged wastewater meets quality standards is becoming increasingly relevant in China. In 2015, a new Environmental Protection Law was implemented in China, increasing COD daily violation fines by 30 times.[410] The fee can now be as high as CNY 84,000 (USD 13,500) for one tonne of COD.[411] This is a daily fine until the violations are corrected. Depending on the extent of the violation, assets may be seized, production limited or the plant could even be closed. Also, discharge permits have been introduced to control the amount of pollutants discharged per year by a company. Polluting is now no longer cheaper than paying for wastewater treatment, which, for small factories, is more economic if done collectively. Better compliance with effluent discharge standards could bring significant improvements to water quality and therefore reductions in costs to the environment and society. Such costs are substantial. In 2015, 3.12 million tonnes of COD were discharged into the Yellow River, resulting in a COD intensity around 21% higher than the national standard.[412] According to the Yellow River Basin Water Resources Conservation Bureau and experts, the economic loss caused by industrial water pollution over the past years was between CNY 13 and 15 billion (USD 2.1 and 2.4 billion) a year.[413] These costs were attributed to agricultural losses (decline in product quality), water resource value losses, public health costs, and additional investment in wastewater treatment plants.

RESOURCE EFFICIENCY IN HOUSEHOLDS

Efficient wash care practices

Efficient wash care practices refer to the resource-efficient practices that households can take when washing textiles. A survey conducted in Beijing and Shanghai showed that, on average, 30,000 litres of water is being used per year per household for washing, with handwash and machine washing taking up equal shares. [xi,414] From the total water consumed per year for washing, around 80% is for rinsing.[415] Households use an average of four rinse cycles to get rid of detergents to ensure the removal of chemicals that are believed by citizens to be harmful to the body.[416] With China's economic growth, it is expected that daily water consumption in urban households will only increase, so smart metering could have a role to play here.

A reduction in household water consumption during washing[xii] could be achieved through greater awareness of resource-friendly laundry practices.[417] These include the use of larger loads and more resource-efficient washing machines, as well as indicating on clothing labels, adverts or detergent packaging what the optimal wash cycle is for different garments. Such measures may not only help save water but may also help preserve the quality of the fabric.

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xi This assumes an average machine has a 50-litre water capacity, while the average handwash basin uses 8 litres of water. In China, although 65% of households in cities own a washing machine, the majority tend to wash both by machine and hand. According to a study by KAO, a Chinese xxxx company, handwash is carried out almost every day or even twice a day, while machine wash is once or twice a week.

xii Currently, household rinsing represents around 80% of the 30,000 litres of water consumed per year for washing. An average of four rinse cycles are done to get rid of the detergent to ensure the removal of chemicals that are believed by consumers to be harmful to the body and skin. With handwash being the preferred method for washing in China, many choose to soak and scrub clothes by hand for the removal of stains or when they have a small load. For machine washers, a survey showed that around 50% of urban households mainly made use of the economy wash programme.

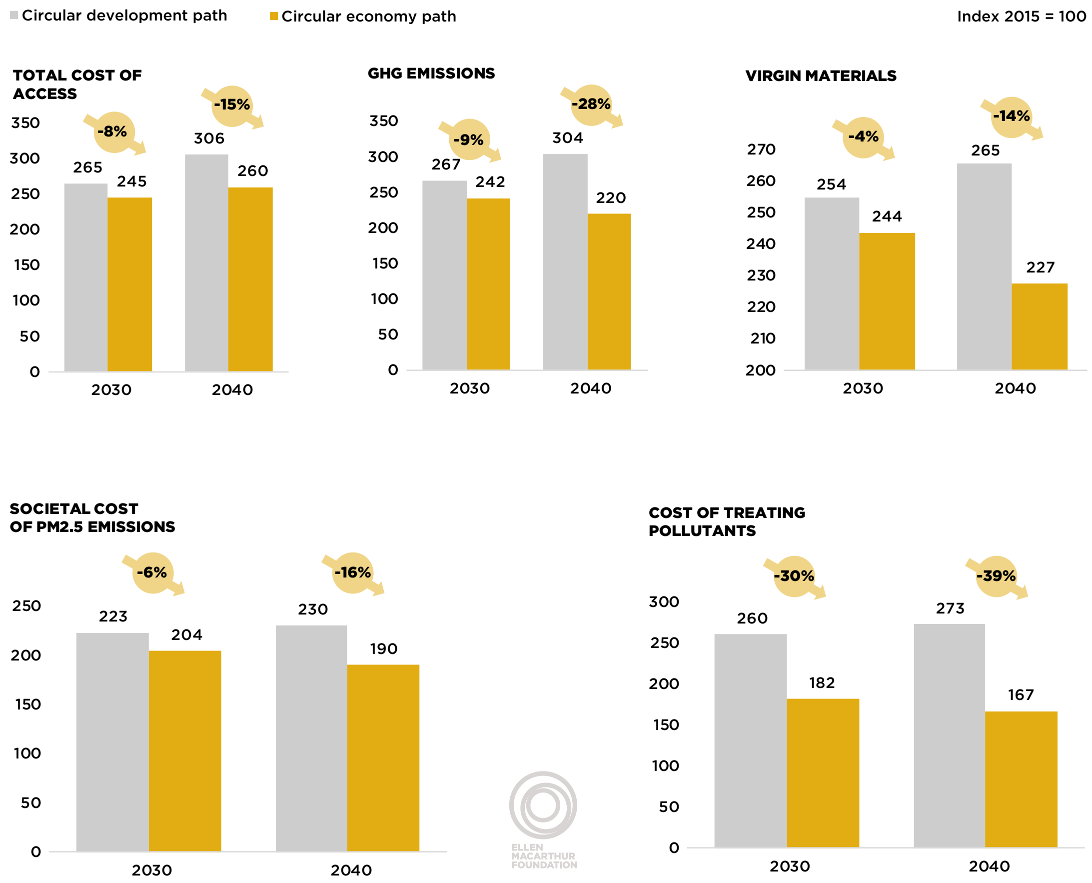
CASE STUDY 4: CLEAN BY DESIGN

Initiated by China's Natural Resources Defence Council (NRDC) and implemented in the cities of Shaoxing and Guangzhou, the Clean by Design programme is a good demonstration of how prosperity can be achieved in the textiles industry through the application of more circular approaches, in this case to the water systems of the cities' textile mills. The benefits of this are manifold – reduced water, energy, and chemical use, as well as increased profits.

At the core of the programme are Ten Best Practices, developed by experts in five Chinese pilot mills and then tested on a wider scale. The practices are "easy to implement, low cost, quick return" measures that are profitable and reduce environmental impact.[418] Enabled by smart metering, most of the practices comprise looped water systems or resource recovery from 'used water' such as the recovery of condensate, reuse of cooling and process water, and recovery of heat from hot water. The programme targeted 33 mills in the two cities. All were required to actively track their water and energy systems, set benchmarks for usage, and design and implement plans for improvements based on the Clean by Design principles. In total, the programme implemented 53 projects leading to positive results across a number of operational areas. The average reduction in water use was 9%, with the best mills achieving a 20% reduction. Total water savings amounted to 3 million tonnes of water. Average energy consumption fell by 6% and in some cases energy reduction was as high as 10%, with total savings equivalent to 61,000 tonnes of coal. Economic benefits totalled CNY 91.6 million (USD 14.7 million), with payback time on investments ranging from 6 to 38 months.[419] As a result of the changes, the use of 400 tonnes of chemicals was avoided, leading to both cost savings and a reduction in the risk of environmental contamination.[420]

There are an estimated 15,000 textile mills in the rest of China. If the savings experienced in the 33 mills in Shaoxing and Guangzhou were extrapolated, the water use of the entire Chinese textiles industry could be reduced by almost 50%. In the years to come, the global textiles industry will naturally gravitate towards developing countries. If China's textile companies master effective water and energy systems in their own mills, the sector might be in a very strong position to export circular knowledge to these countries, ensuring that textiles production in countries like Cambodia follows circular principles from the outset.

A CIRCULAR TEXTILES SECTOR: THE BENEFITS FOR CHINA'S CITIES



CALCULATING THE BENEFITS

Current development path
In the current development path we assume the trends of increasing population, size of middle class, and disposable income will influence household textile consumption in ways similar to those seen in the US and Europe. For example, a rise in prosperity is expected to lead to an increase in consumption and wastage.[421] We further assume that the following key policies and targets are implemented:

- The Water Ten Plan: China's State Council has prioritised the textiles sector as one of ten industrial sectors in which to initiate circular measures. The Water Ten Plan was issued in 2015 with the aim of combatting heavy water consumption and pollution by setting objectives to be met by 2020.
- The 13th Five Year Plan (2016–20): This plan has provided the textile industry with clear targets regarding water and energy consumption as well as strict COD standards.

Circular economy path
The circular economy path reflects the impact of the circular economy opportunities identified for the textile industry in 2030 and 2040. In 2030, it is assumed that tangible near-term opportunities have been achieved. For 2040, a more ambitious scenario has been envisioned based on optimistic penetration rates, stakeholder and cross-sectoral collaboration, technological and material innovation, and behavioural shifts. For example, a 41% collection rate for textiles was modelled in 2030 (using the present UK rate as a benchmark), while a 56% collection rate for textiles was envisioned in 2040 (three-quarters of the present 74% German rate).[422]

Total cost of access (TCA)[xiii] to textiles for China's urban population could be reduced by CNY 0.5 trillion (USD 80 billion) in 2030 and CNY 1.2 trillion (USD 193 billion) in 2040 through the implementation of circular practices. This is an improvement over the current development path (CDP) of 8% and 15% respectively. The main drivers for these gains are pursuing business models that increase the utilisation of durable textiles, and increasing water recycling and water treatment. Together these opportunities are responsible for 76% of the 2040 total TCA savings. Externality and cash-out cost savings represent 55% and 45% of total TCA savings in 2040 respectively.

Increased utilisation of durable textiles will realise the greatest benefits in total cost of access (TCA), generating CNY 0.5 trillion (USD 80 billion) in savings by 2040, and is responsible for 76% of total cash-out savings

The main driver of the circular economy TCA benefits for 2040 is the increased utilisation of textiles through new business models. Textiles would be designed to last longer while new business models would increase the average number of times they are used or worn. By 2030, it is assumed, however, that only a small share of the population and businesses will be reusing textiles. With present hygiene concerns and society's growing interest in fast fashion and high-quality goods, there is a social barrier to wearing second-hand clothes or renting clothes. For businesses, the leasing and renting of textiles, garments, fabric or yarn is still in its infancy. As a result, it is assumed that by 2030 the rate of increase in textile utilisation will be moderate.

By 2040, the sharing economy in China is expected to have rapidly picked up in popularity across sectors. People will have warmed up to the concept and with a rise in the middle class and e-commerce, the renting of high-value garments will become increasingly convenient and appealing. It is assumed that, by 2040, about a third of the textiles used by 20–30% of the population and businesses will have been used before. With a rise of individualism,[423] people may also increasingly patronise retailers that offer customised or personalised clothing, having the effect of limiting over-production and extending garment use. With renting and leasing already picking up in the markets for luxury and special occasion garments, interest may grow for similar approaches to other garments, such as baby clothing and sportswear, that have short-term uses. For the home and technical textile sectors, greater opportunities would be found in B2B markets. The opportunities are assumed to exist alongside the production of durable textiles.

Increased water recycling and water treatment will generate CNY 0.4 trillion (USD 64 billion) in TCA savings by 2040, and is responsible for 60% of total externality cost savings

Implementing all the circular economy textile opportunities has a significant impact on reducing externality costs. The circular economy scenario generates externality cost savings, compared to the current development path, of CNY 0.4 trillion (USD 64 billion) in 2030 and CNY 0.7 trillion (USD 112 billion) in 2040.

While all of the circular activities contribute to this impact, the main driver is increased water recycling and treatment, which contributes 60% of the 2040 cost savings (CNY 0.3 trillion ~ USD 48 billion in 2030 and CNY 0.4 trillion ~ USD 64 billion in 2040 compared to the current development path). This assumes recycling rates of 37% in 2030 and 40% in 2040 and full compliance with water quality discharge standards. The large savings are related to the fact that the textile industry at present is one of the most polluting and water-intensive in China, meaning there is large scope for improvement. The circular economy scenario sets out an ambitious increase in water recycling and treatment since

xiii Total cost of access (TCA) is made up of cash-out costs and externality costs. Cash-out costs exclude government subsidies and incremental capital expenditure (the added investment needed to move to the circular economy scenario). Externality costs represent the economic costs, such as lost earnings and healthcare expenditure, associated with, for example, emissions of greenhouse gases and particulates. Details can be found in the Technical Appendix.

mandatory measures, stringent standards, policies and pilots are already in motion in China, meaning the enabling conditions and technology are already largely in place.

Stimulating automation and 3D printing, water and energy efficiency, and textile recycling decrease the need for virgin materials and other primary resources, while generating CNY 0.3 trillion (USD 48 billion) in savings by 2040

In a circular economy scenario, Chinese urban households could benefit from cost savings of CNY 0.1 trillion (USD 16 billion) in 2030 and CNY 0.3 trillion (USD 48 billion) in 2040[xiv] from automation and 3D printing,[424] water and energy-efficiency practices,[xv] and recycling.[xvi] Stimulating innovation and upscaling the implementation of such technologies and practices across the industry ensures the productive and efficient use of resources, while reducing externality costs. Since automation is at the forefront of China's industrial revolution, it is expected to be fully embraced by 2040 in the textiles industry. This would allow for increased output yields through higher precision work that reduces waste and raw material costs.[425] In addition to cost savings, automation and 3D printing, water and energy-efficiency practices and textile recycling would also reduce CO_2 emissions by 0.2 billion tonnes by 2040 compared with the current development path.

CONSIDERATIONS FOR THE TEXTILE INDUSTRY IN CAPTURING THESE BENEFITS

Utilising design as a catalyser for value creation and retention

Capturing the economic benefits of recycling requires alignment between textile design and recovery and recyclability through cross-value chain collaboration.

DESIGN FOR DISASSEMBLY

Innovative solutions could enable the disassembly of textile products and help increase their durability and recycling rates. For example, the use of new laser and water-jet technologies could allow for easier disassembly when cutting, etching, and bonding techniques are used. This is because fabric would be welded or sewn together without the use of permanent fastenings like threads.[426] Furthermore, zippers, buttons, and accessories are often difficult to remove before recycling. Dutch Spirit has helped tackle this challenge by designing buttons that can be 'clicked' into and out of fabric, and thus easily removable before recycling.[427] The same principles can be used for textiles that form part of other products. For example, recovering technical textiles such as those used in cars (e.g. safety belts, seats, air bags, and carpets) can only take place if both the textiles and the associated car components are designed for disassembly.[428,429] The approach can also be applied to increasing the use length of textiles. A design challenge has shown that detachable box-pleats, waistbands, and hemlines enable wearers to customise clothes by changing their size, fit and length,[430] thereby potentially prolonging use as needs and tastes change.

DESIGN FOR RECYCLABILITY

Most textiles are not designed with recycling in mind; instead, requirements revolve around functionality and fashion trends such as appearance, comfort, and performance. To meet such demands textiles are often made up of different fabrics, [xvii] containing various fibre mixes.[431,432] For most material blends, adequate recycling technologies are not yet available. To ensure recyclability of textiles, it is therefore crucial to align textile design and available recycling technologies.[433] For example, Dutch Awearness has developed a 100% recyclable textile fabric called Returnity®, which can also offer energy, water, and carbon dioxide savings of 64%, 95%, and 73% respectively, while cutting

xiv By 2040, it was assumed that a resource productivity rate of 3–5% could be achieved.

xv By 2040, it is assumed that the most ambitious water- and energy-saving potential obtained in the Solidaridad and NRDC pilots (see section 'Efficient water and energy management', p.100) could be achieved by 70% of the industry.

xvi By 2040, it is envisioned that garments, as well as home and technical textiles, will be separately collected and recycled. Collection systems across cities and technological innovation, sorting and recycling practices will become the norm in China. Collection rates are assumed to reach 56% while enabling recycling rates of 28%.

xvii Blended materials are particularly challenging for bulky home textiles, such as carpets and mattresses, which are made up of multi-layered mixtures of different polymers and inorganic fillers. The recycling yields are low, while their material complexity makes them costly to recycle and their size, costly to transport.

down on raw material demand by 61%, when compared to standard virgin textiles.[434]

Stimulating technological innovation in the recycling industry for higher output quality

Ensuring high-quality feedstock for textile recycling are key to output quality and therefore capturing the value of recovered materials. However, the sorting of collected textiles today is mostly done manually, limiting detection of material types to sight and touch.[435] Furthermore, labels do not always accurately indicate the fibre content in textiles[436] and consumers tend to cut them off after purchase. As a result, incorrect material identification can occur, leading to lower feedstock quality. Furthermore, the vast majority of textile recycling technologies used today reduce the quality of materials, limiting their marketability.[437] Thus, for recycled materials to be able to compete with virgin materials on cost and quality, innovation in sorting and recycling technologies plays an important role. Focus would be needed on improving the recycling of material blends and preventing the deterioration of fibre quality. Where no alternatives to blends can be found that achieve similar functionality or cost, innovation into after-use technologies is necessary. This would allow for much higher recovery rates and recycling quality. The start-up, Worn Again, has developed a process that can separate and recapture polyester and cotton from pure and blended materials into virgin-equivalent polyester and a cellulose pulp that can be used to produce lyocell or viscose.[438] The company claims that the vast majority of non-wearable textiles are suitable as feedstock for their process. The Hong Kong Research Institute for Textiles and Apparel, in partnership with the H&M Foundation, also recently developed a new process to separate cotton-polyester blends.[439] On the sorting side, promising developments are already taking place. For example, Valvan has developed an automated near infrared spectroscopic technology called FIBERSORT that can sort garments by colour and certain fibre blends at the same time.[440,441] If such technologies are used within a system in which product passports, material labelling, and tracking and tracing are the norm, they would allow for a more transparent, efficient, and effective sorting of a greater share of textile types.[442]

Driving market demand for recycled materials

To enable effective markets for recycled materials, it is critical that recycled materials fulfil buyers' quality and price requirements. Transparency would be needed regarding such requirements and the properties of materials, so that buyers develop trust in recycled feedstock,[xviii] and there is better matching of supply and demand.[443] Brands are in a good position to drive this demand by creating a 'pull' effect. Policymakers could further incentivise the use of recycled materials,[444] for example by favouring them – and providing information on them – in public procurement guidelines. Increased demand would bring about economies of scale in the production of recycled materials, improving their competitiveness with virgin alternatives.[xix,445]

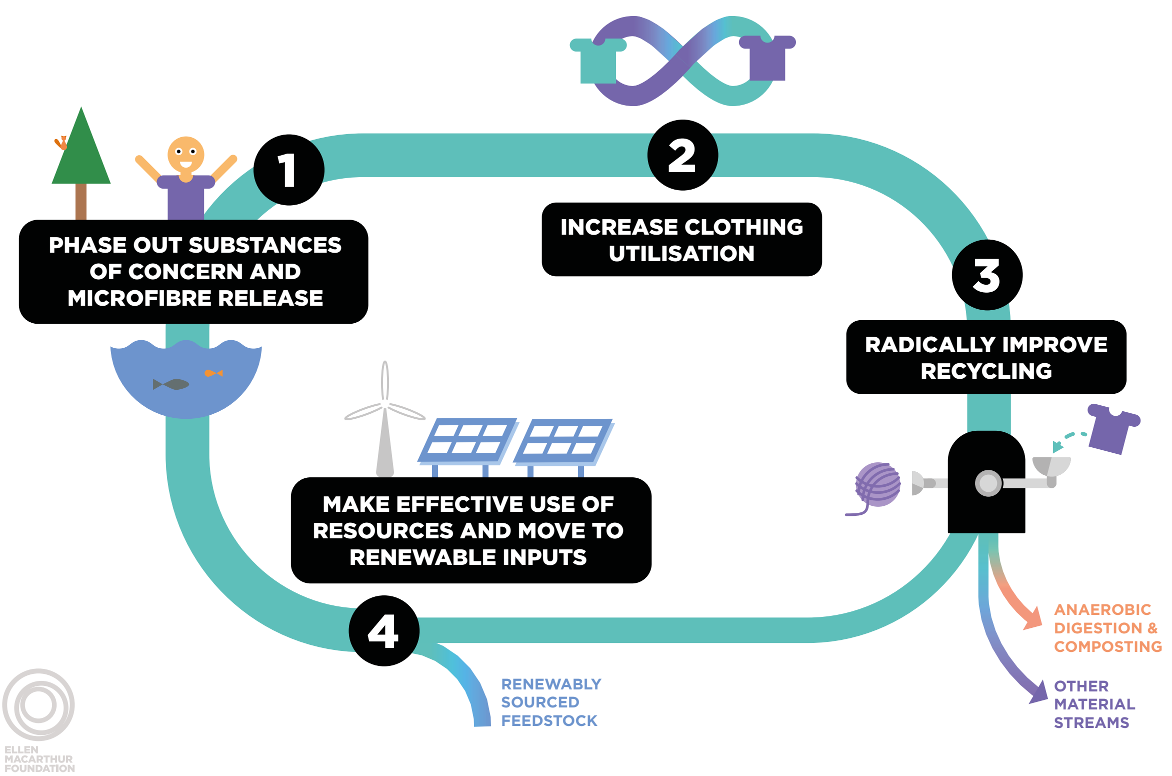
xviii The uptake of virgin-quality recycled fibres in the technical textile sector could be stimulated if transparency is ensured regarding recycled material quality, property, and material composition. The sector utilises high performance fibres carefully selected for their quality and functionality. Though technologies still need developing within the recycling industry, it is an untapped sector that presents a potential new market for virgin-quality recycled fibres.

xix Chemical recycler, Zhejiang Jiaren New Materials Company has already managed to decrease the price of their recycled fibres by around 50% in the space of three years. They are confident that, in the coming years, the price of recycled fibre could become more cost competitive to virgin materials.

A SYSTEMIC APPROACH TO A NEW TEXTILES ECONOMY

While this chapter looks at circular economy opportunities that can be captured by the Chinese textiles industry, there are further benefits to be gained by acting globally. The Ellen MacArthur Foundation report *A new textiles economy*[446] presents a systemic vision for the global textiles system, focusing on fashion. A new textiles economy is one in which clothes, fabrics, and fibres are kept at their highest value during use, and re-enter the economy after use, never ending up as waste. Such a system would provide a growing world population with access to high-quality, affordable, individualised clothing, while regenerating natural capital, designing out pollution, and using renewable resources and energy. It would be distributive by design, meaning value is circulated among enterprises of all sizes in the industry so that all parts of the value chain can pay workers well and provide them with good working conditions. This systemic vision has four core ambitions, aligned with the principles of a circular economy and illustrated in Figure 4 below.

FIGURE 4: FOUR AMBITIONS FOR A NEW TEXTILES ECONOMY



Source: Ellen MacArthur Foundation, *Towards a New Textiles Economy*, (2017)

ELECTRONICS: REDESIGNING PRODUCTS FOR REUSE AND RECOVERY

China has become the world's foremost producer of consumer electronics and household appliances, accounting for almost 40% of global output. It is also one of the world's largest markets for these products, with demand expected to grow as incomes swell and more households join the middle class. However, the consumption of a high, steadily rising volume of electronic goods has unwelcome consequences. Every year, some 6 million tonnes of domestically consumed electronic products are discarded. While the methods commonly used in China to process e-waste allow valuable materials to be recovered, they also have harmful effects on the environment and public health. To maximise value recovery in electronics while minimising negative effects, China's cities could seize circular economy opportunities. One such opportunity is to recover more value from e-waste by improving collection practices, imposing order on the informal network of e-waste recyclers, and by modernising many of those processes. A second is to expand capacity to reuse discarded electronics and appliances that are still functional, and to recover useful components from whole products that no longer have value, while bolstering the margins of such activities with updated, circular product design practices. A third is to apply circular design practices to enable new business models that discourage disposable products and encourage a restorative approach to raw materials and finished products. Product-as-a-service concepts, in particular, allow people and households to pay for the use of electronics and appliances, rather than buy and own the devices themselves. Taking these opportunities could transform China's currently resource-hungry and wasteful electronics sector into a world-leading industry that is not only innovative in its products, but also forward thinking about its use and after-use cycles.

China is a major manufacturer of consumer electronics and appliances. Producing 39% of the world's electronics,[447] the country is home to some of the largest manufacturers in this space, including Haier, Huawei, Xiaomi, and Lenovo. Around a third of China's production is exported, mainly to the US and Europe.[448,449] This export production is highly concentrated along the coastal provinces in the east of China, such as Shandong, Jiangsu, Anhui, and Guangdong.[450]

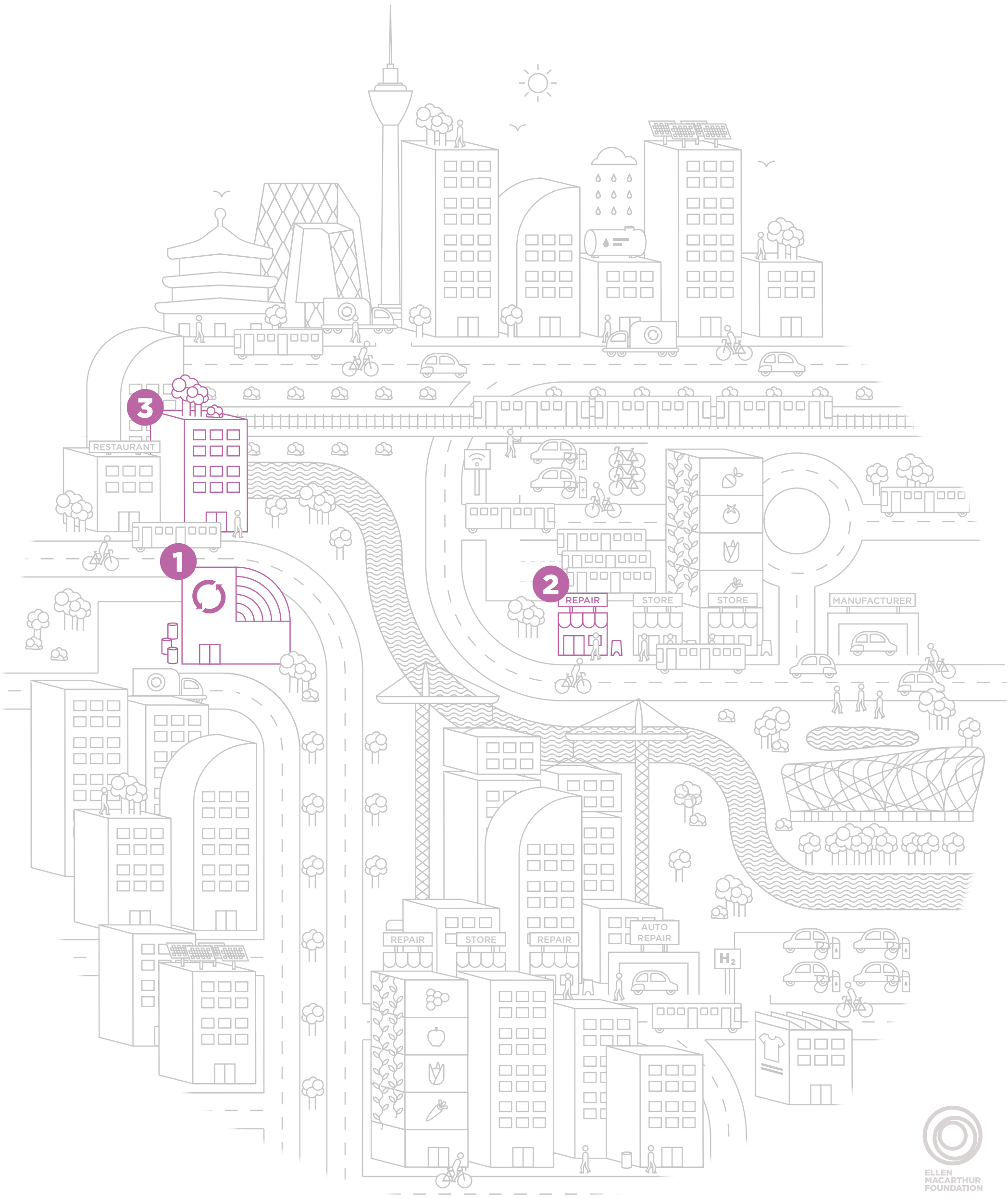
China's production capacity creates enormous demand for raw materials. While the sector's consumption of steel and non-ferrous metals might be small in comparison to that of the automotive and construction industries, it is one of the leading consumers of precious metals, rare earth elements, and some of the metals and minerals described by governments around the world as 'critical', such as gallium and cobalt. Historically, China's makers of electronics have obtained most of the raw materials they need from domestic sources. For 18 of the commodities deemed most important for the world economy, and most popular among investable mineral commodities, China's domestic mining output is the first or second largest in the world. However, this level of domestic mining activity has a 'burn rate' that indicates the country will experience bottlenecks in its proven reserves in the next few decades.[451] Many elements of China's raw material strategy therefore focus on finding and securing new sources overseas.[452] China is also exploring ways to recover more materials from e-waste as an alternative to imports. The central government is aiming to strengthen supplies of materials not only through the development of the e-scrap industry, but also by regulating the flow of secondary materials. For example, the magnets recovered from discarded computer hard disks (before solid state technology entered the market and did away with the need for them) cannot be exported legally because they contain valuable metals that are important inputs to China's manufacturing industries.

China is one of the world's biggest markets for electronics and appliances. Demographic and economic trends have created a new and growing Chinese middle class, whose tastes are driving an increasingly strong domestic market for China's manufacturers. For example: 71% of urban Chinese citizens now own a smartphone;[453] the market for TV sets increased by around 50% from 2005 to 2015;[454] and in recent years an additional 35–40 million new washing machines have been acquired by Chinese households every year.[455] Unsurprisingly, much of this consumption is concentrated in the large cities. Currently, these are mainly in the coastal areas, where the manufacturing of electronics and other products has driven rapid urbanisation and income growth. A continuation of westward development under China's One Belt One Road plan means that more workers remain living in, or return to, manufacturing bases closer to home. The penetration rate of electronic devices that results from this growth still lags behind the US and Europe, and further growth is therefore to be expected. Moreover, the newfound tastes and means of China's urban middle class have in the last few years not only resulted in a larger number of electronic items sold, but also to higher levels of quality and price.

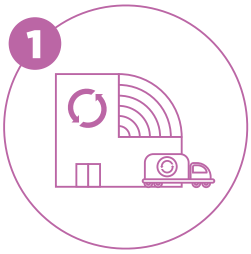
China is facing challenges in the disposal of its domestically produced, and imported, e-waste. Every year, an estimated six million tonnes of domestically consumed products are discarded.[456] Moreover, China has over the years imported large volumes of e-waste. While domestic waste and imported waste frequently find their way into recycling channels – often concentrated in a few urban and peri-urban areas – these are often under-equipped. One such case is the stripping of cables in order to access the precious copper within, which is commonly done by simply burning off the insulation layer in an open pit fire, releasing toxic fumes from the flame retardants in the insulation.[457] Another is the leaching of motherboards to recover mainly gold, silver, and palladium is often executed using dangerous chemicals. Such practices incur negative externalities such as soil pollution.[458] Recent policy efforts, such as the 2017 National Sword campaign, aim to tackle the recycling challenges associated with domestic and imported electronic scrap.[459]

VISION FOR A CIRCULAR ELECTRONICS AND ELECTRICAL APPLIANCES SECTOR IN CHINA

With its high concentration of electronics production in just a few clusters and a population with a penchant for electronics and electrical equipment, China's urban environment presents an optimum opportunity for a circular electronics landscape. In a circular system, consumer goods, such as electronics and appliances, would be produced and enjoyed in a way that amplifies any efficiency gains in its manufacturing by keeping products and components in some form of active use for a longer time. China's urban families, which in such a system become users rather than consumers, could access goods through a variety of models that provide utility at a lower cost without compromising on convenience. When their products could no longer be useful in any shape or form, citizens would find ample, practical opportunities around the city to part with them so they can be safely recycled.



CIRCULAR ECONOMY OPPORTUNITIES



Capture the value of e-waste through recycling

China's electronics recycling could benefit from upgrades and improvements along its entire value chain, including increased formalised collection rates, a consolidated pre-processing sector that adopts better practices, and a switch from manual to industrial end-processing.

Increase formal waste collection rates. China already has a sizeable e-waste recycling industry. However, it is fraught with challenges along the value chain. A significant part of the collection effort occurs in informal channels. In the past, the government has undertaken several initiatives in an attempt to formalise collection activities. For example, the NDRC's Home Appliance Old for New Rebate Program (2009–11) provided new-purchase discounts to citizens who disposed of appliances through government-subsidised collectors. This programme had faced significant operational challenges as there is not a collection system in place that ensures a constant supply of waste.[460]

Three types of intervention could contribute to higher formal collection rates that complement rather than replace informal collection. New ventures that include collection as an essential activity in their refurbishing or recycling business schemes could enter the market. One example is Aihuishou, which collects used phones through a buy-back model — it already collects on average more than 13,000 phones each day.[461] Public policies could reinforce manufacturer responsibility for the end-of-use (EoU) fate of devices, and established original equipment manufacturers (OEMs) could decide to launch their own complementary collection programmes for both environmental and supply chain reasons.

Optimise the structure and practices of the pre-processing market. Given that informal collection practices are already in place and formalising them takes considerable effort, the government has more recently shifted its focus towards formalising other parts of the value chain.[462] The recycling process consists of a pre-processing step in which products are shredded or disassembled in order to access various materials, and a processing step in which precious metals and other materials, including ferrous and non-ferrous metals, are recovered. Both steps come with considerable environmental and human health costs when handled incorrectly.

The pre-processing market in China is highly fragmented, with 109 licensed companies and a large number of small private companies and informal workers. The performance of these companies varies widely, both in terms of volumes treated and value extracted. Care for the environment and the health of workers and the public is not consistent either. Pre-processors have access to all collected volumes and because trades are usually in cash, they can access volumes from both formal and informal collectors. Increasing the rate of processed e-waste and formalising and consolidating the e-waste pre-processing industry would substantially increase the availability of precious, ferrous and non-ferrous metals, and dramatically reduce pollution and other negative externalities mostly linked to informal processing. Such consolidation is in any case desirable due to high cash-flow (requirement both upstream and downstream) and the typically strong competition for e-scrap feedstock within a region.

This opportunity entails optimising pre-processing practices. Initially, this would require adding a manual step before the automated-only shredding that, where appropriate, would separate highly valuable pieces from the product before shredding takes place. The industry would also need to move from informal practices to a more formalised approach for both pre-processing and processing activities. Both shifts strive to enable a higher yield, especially of precious metals. From 2012 to 2015, CNY 16.4 billion (USD 2.6 billion)[463] in subsidies were distributed to the 109 licensed pre-processors to support such a transition.[464]

Several companies in China are already venturing in this direction. Under the incentive of a government R&D grant, urban mining and recycling company GEM is deploying cutting-edge technology to increase its extraction rate, and is obtaining its raw material (e-waste) from suppliers that collect discarded products. Such a development is strongly encouraged by the government. Other steps the government has taken include limiting the number of companies that can legally pre-process certain e-scrap fractions such as air conditioners, computers and — most recently — smartphones.[465,466] The larger volumes these companies can therefore access could enable them to invest in both yield-improving technologies and environmental controls.

Formalise the final processing phase of the e-waste value chain. In addition to pre-processing, the processing step would also benefit tremendously from professionalisation and formalisation. About 99% of printed circuit board (PCB) scrap coming onto the market in China is processed domestically. The country has a total formal PCB scrap processing capacity of 342 kilotonnes a year, but no information is available on the actual capacity in operation. GEM, Dazhou Env. and Sound Recycling together represent approximately 25% of this market. Current backyard procedures perform significantly less well than industrialised ones. For example, whereas backyard smelting is typically able to recover 25% of the precious metal in the scrap, China's copper smelters can extract up to 70% and European and Japanese smelters have developed a specific e-waste activity, which have a precious metal yield of 95%.[467] Moreover, and of at least equal importance, industrial smelters have invested heavily in environmental controls, whereas backyard smelting creates irreparable damage to local soils and water bodies, and has negative impacts on the health of workers and their families, who often live among these backyard activities.

Further innovations could improve the processing landscape and its performance. For example, the emergence of viable closed-loop hydro-metallurgical processes could allow for a decentralisation of the end-processing step (which is currently highly concentrated due to the large investments required for smelters). This in turn could open up options for vertical integration and other forms of local/regional collaboration that could bring down costs across the reverse value chain.

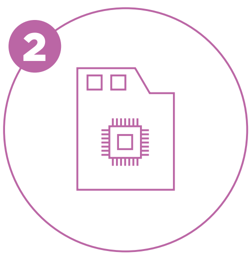
Finally, options also need to be created for less valuable materials.[i] The average electric or electronic device has a plastic content of about 30%,[468] and two million tonnes of domestic plastic e-waste were generated in China in 2014.[469] While some plastic components are dismantled for reuse, only 28% of regulated e-waste, including plastic, is collected and processed through the official take-back system.[470]

i Not included in the quantitative modelling of this report.

CASE STUDY 5: SHANGHAI: A MULTI-PARTY, MULTI-CHANNEL APPROACH TOWARDS 'URBAN MINING' OF E-WASTE

The city of Shanghai, a pioneer when it comes to achieving higher formal collection levels by integrating both online platforms and offline logistics,[471] has been establishing a comprehensive collection system[472] while also experimenting with emerging online-to-offline e-waste collection platforms.

- **Early private sector initiative.** Jinqiao became the first company certified by the city to receive subsidies from the e-waste fund. It created the online platform Alahb to enable urban residents to donate their e-waste either through drop-off at one of the 2,643 collection points or online appointment for home pick-up. Citizens who do so can be rewarded with credit on an Alahb card, which can be cashed out through China Everbright Bank.[473] As powerful as the internet-based platform might be, effective offline logistics are also crucial. Selot was the first company in the country to establish an effective network of collection points across the city (now across all 16 districts as well as 104 industrial zones). It takes advantage of a network of retail stores where people can drop off their e-waste, as well as convenient store locations where a pick-up service can be arranged for larger electrical appliances. There are now 24 million residents with access to 527 traditional collection points. Four warehouses and 40 vehicles[474] also help to solve the 'last mile' problem of collection.
- **Ample municipal government support**. Shanghai municipality's active engagement provides great support for the local e-waste collection and treatment initiatives. It is one of the first cities in China to initiate actions on e-waste and to have included "establishing an e-waste collection network" in its municipal planning.[475] Various departments of the municipality also collaborate to promote the development of the e-waste sector: the Ministry of Environmental Protection (MEP) is in the lead in terms of managerial/regulatory bodies at both city and district level, with a focus on establishing the connection between collection and processing. They also closely monitor the operations of processing industries to make sure that they meet the required environmental standards. The Development and Reform Commission (DRC) oversees circular economy implementation from a higher level while the commerce department takes care of the recycling system for secondary resources in general, but with a specific focus on e-waste. Needless to say, the finance department's role in securing and distributing funds for these actions is also crucial.[476]
- **Engaged citizens**. Shanghai's e-waste successes can also be attributed to the successful engagement of Shanghai's citizens. Selot has hosted more than 2,000 educational events in the city to raise public awareness;[477] the collaboration with China Everbright Bank economically incentivised residents to separate their e-waste from other wastes; and the network of online and offline collection channels lowered the threshold for participation.



Reuse and refurbish products, and remanufacture parts

A safe and effective e-scrap recycling industry is critical in a circular production and consumption system, yet this is not where the biggest economic opportunity lies. As explained in Chapter 2, a circular economy creates value not only by retaining materials in the system, but also by retaining more of the value that was added during manufacturing. This is especially true for complex products like appliances and electronics, where the raw materials represent only a fairly limited part of the total value of the final goods. For example, a typical smartphone has a raw materials content of less than CNY 100 (USD 16), so recovering more than just materials should yield significant value.

In recent years, the emergence of outfits and schemes such as that of Aihuishou has started to create new pathways for end-of-use (EoU) electronics in China. Aihuishou will, after assessing the condition of every phone it collects, either refurbish it in order to put it back onto the market, or remanufacture it and extract the functioning parts, which it sells to brokers and manufacturers with the aim of returning them to the manufacturing process. To date, Aihuishou has attracted more than CNY 500 million (USD 80 million) in investment.[478] The Chinese government is also interested in strengthening these 'tighter loops'. In addition to its efforts to improve the environmental and financial performance of the recycling industry, it is also looking into stimulating reuse and remanufacturing pathways. Two major circular economy approaches – reuse/refurbish and remanufacturing – stand out as being particularly beneficial for the electronics and appliances sector. Both could be bolstered by a more deliberate approach towards quality control in this secondary supply chain and a product design approach that is geared towards easy disassembly and reassembly, fault diagnosis, and repair.

Encourage the reuse and refurbishing of electronics and appliances. With these practices, discarded or returned products are inspected for their overall state of wear and tear and, if found satisfactory, they are returned to the (secondary) market through various alternative distribution channels. Some cleaning or minor refurbishing may be needed in order to find a market, but often it is merely a matter of rechannelling goods. This is especially the case for products that are deemed unmarketable due to packaging damage (e.g. from poor shipping conditions) or that have come back through an authorised returns programme. In this case, repackaging might do the trick, but so would developing sales channels where shoppers do not expect impeccable packaging – a simple trade-off for an attractive price point, allowing a wider range of households to access electronics and appliances.

Expand remanufacturing and parts harvesting of electronics and appliances. These practices allow consumers and companies to recover value from products and parts (commonly called 'cores' in these reverse logistics schemes) that are in a condition that no longer allows for simple reuse. However, some valuable parts (e.g. the camera in a smartphone or the heating block or pump in a coffee machine) can still serve their original purpose or an alternative one. Manufacturers and third-party service providers can therefore retrieve these parts and put them back into their own, or an alternative, manufacturing process.

Obviously, these tighter loops do not do away altogether with the need for well-performing recycling industries. While value could be maximised by shifting discarded volumes to these higher-end reuse and remanufacturing channels, a significant amount of product will continue to come back in a condition for which material recovery is the most expedient option — both environmentally and financially.

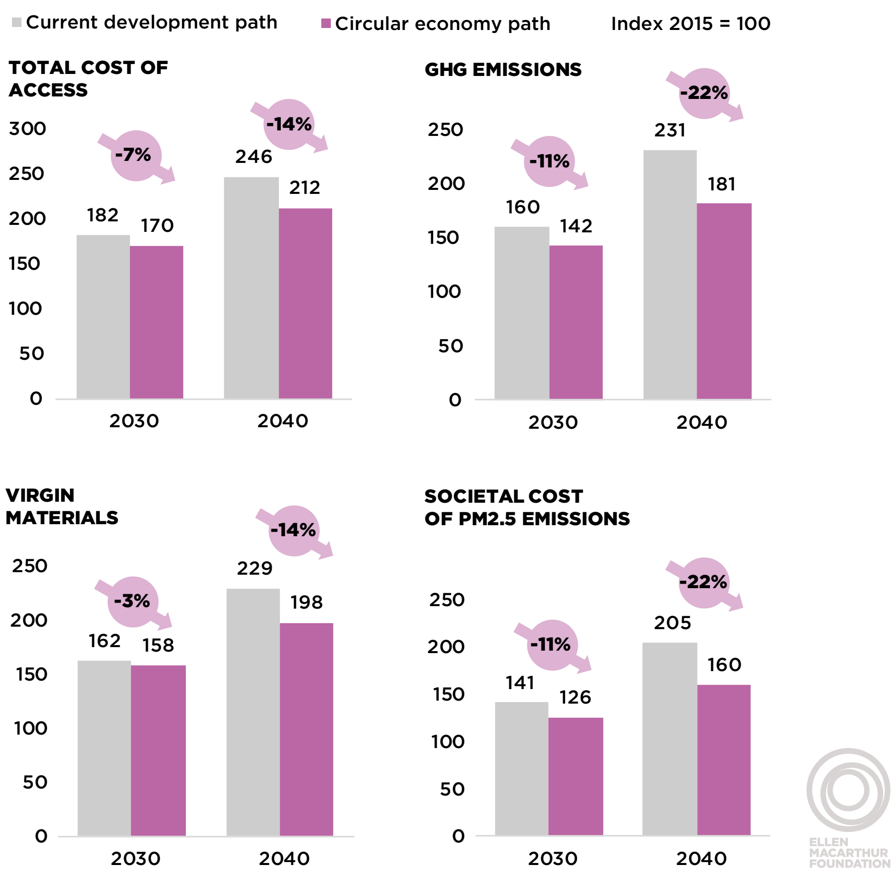
Encourage product-as-a-service models

A major source of inefficiency and waste in the area of electrical and electronic devices stems from today's usage models. People tend to own whatever device they want to use, however infrequent that usage might be. For example, according to global averages, across their entire lifespan, washing machines are idle for more than 80% of the time. In China, where families continue to make ample use of handwashing even after the acquisition of a washing machine, this idle time is likely to be even higher.

There are alternatives to this conventional ownership model. Product-as-a-service (PAAS) meets the needs of a given user base with a smaller number of products. Rather than relying on outright sales of the product itself, OEMs and/or intermediaries sell the service but retain ownership of the asset. Two interventions are most relevant for the sector: shifting to sharing models; and shifting to pay-per-use (PPU) models. These models are not necessarily independent: a product like a washing machine, for instance, can be offered to various users simultaneously (sharing) on a pay-per-use basis. While the central government seems to be generally supportive of sharing models and the Premier Li has spoken out about them multiple times,[479] to date, only limited regulations or other formal policies have been put in place.

In PPU models, users do not have to be owners. Instead of paying upfront for a single purchase, customers pay over time based on the number of times they use a product or benefit from it, which is why such set-ups are commonly called 'access models'. These models have been the focus of considerable entrepreneurial activity. A few suppliers of cars, bikes, homes – even umbrellas – are striving to grow these markets. In electronics, the shared charging of phones has seen a significant infusion of capital. In just two months in the spring of 2017, the top three companies in this space at the time – Laidian, Xiaodian, and Jiedian – attracted more than CNY 790 million (USD 127 million) in investment.[480] Street Electricity is a good example of a PPU model in the electronics sector, as it puts a number of portable chargers inside shopping malls and makes them available to any users who deposit CNY 100 (USD 16) into the app. Users do not need to purchase a portable charger to use it, they only register and pay for every use in a convenient, low-friction way without subscription. Street Electricity maintains control of the daily operations and maintenance of these chargers. On the appliances front, smart, shared washing machines have recently popped up in the streets of central Shanghai. While the value of laundry services in the middle of the street rather than behind a storefront or residential facade might be questioned, this initiative highlights the force for change that China's ultramodern payment systems represents, as Shanghai's citizens can pay to use the machines through WeChat and Alipay.

A CIRCULAR ELECTRONICS AND ELECTRICAL APPLIANCES SECTOR: THE BENEFITS FOR CHINA'S CITIES



CALCULATING THE BENEFITS

Current development path
In the absence of dedicated interventions, the projected growth in the production and urban consumption of electronics in China, propelled by demographic and economic changes, would be paralleled by strong growth in the total cost of access (TCA), to almost double what it is today, by 2030. Over the same period, resource requirements would more than double and associated externalities increase by 50%. The Chinese government's policies focusing on end-of-use (EoU)[2] flows of electronic devices – aimed at keeping discarded electronics out of the waste stream and protecting the environment, but also designed to create viable material recovery options – are increasingly coming into place, but since most are not part of the 13th Five Year Plan their contribution to the current development path (CDP) scenario is limited.[3]

Circular economy scenario
In the circular economy scenario, the scope and penetration of the three main opportunities is widened beyond what could be attributed to policies and targets that are set in the five-year plans. This is partially based on what can be observed internationally for the EoU levers, and on product and usage characteristics for the new business models. This scenario is based on two key assumptions. For unleashing the value in e-waste (recycling and processing) and Keeping products in tighter loops (refurbishing and reuse) the 2030–40 period sees fast growth mainly due to a doubling in collection rates and a change in the distribution between recycling on the one hand, and refurbishing and remanufacturing on the other (this shifts from 100/0 in 2015 to 76/24 in 2030 and 25/75 in 2040). For redesigning business models each of the 25 products in the impact model was assigned to an archetype in order to assess how

The implementation of circular practices in the electronics and electrical appliances industry could bring about CNY 0.2 trillion (USD 32 billion) by 2030 and CNY 0.6 trillion (USD 96 billion) by 2040 in total cost of access (TCA)[ii] reduction for China's cities. This is an 7% and 14% improvement over the current development path (CDP) scenario. Across levers, 82% of 2030 and 2040 TCA savings come in the form of reduced cash-out costs and 18% are the result of reduced externalities, such as reduced greenhouse gas emission, as well as particulate matter PM2.5 by 11% in 2030 and 22% in 2040.

Going circular in the electronics sector can create benefits beyond currently proposed policies. Combining the three circular economy opportunities — better recycling, higher-value EoU options, such as remanufacturing, and alternative business models — by 2030, could yield a TCA reduction of nearly 7% compared with the current development path. By 2040, this reduction could be a 14%. By then, about half of this contribution could be achieved through alternative business models. This comes with a reduction of 24 million tonnes of CO_2 emissions and a reduction of the particulate matter PM2.5 by 11% in 2030. Importantly, the industry's reliance on key virgin raw materials such as precious metals could be reduced by 14% in a circular economy scenario in 2040.

There is a compelling economic case for circularity in the electronics sector. EoU schemes can be profitable if particular attention is paid to raising collection rates and optimising the fate of EoU electronics and household appliances. Higher collection rates bring scale and, consequently, lower costs to any EoU business. Ultimately, by channelling devices into the right EoU process, more of the materials' added value and profitability is retained. Based on an increase from the current margin of 15–45% to a steady 45% in the formal collection rate across appliances, computers and peripherals, mobile phones and other personal electronics, the total system benefit of implementing circularity could be CNY 0.2 trillion (USD 32 billion) by 2030.

ii Total cost of access (TCA) is made up of cash-out costs and externality costs. Cash-out costs exclude government subsidies and incremental capital expenditure (the added investment needed to move to the circular economy scenario). Externality costs represent the economic costs, such as lost earnings and healthcare expenditure, associated with, for example, emissions of greenhouse gases and particulates. Details can be found in the Technical Appendix.

Full circularity in the electronics system could become a new source of competitiveness for China. There are further opportunities for China in the transition to a circular economy. For example, circularity-inspired improvements within the supply chain itself, such as the internal recycling of water between various applications in the semi-conductor industry, or the picking off and reusing of components of boards that do not pass quality inspection, could create additional value in the electronics system.

CONSIDERATIONS FOR THE ELECTRONICS AND ELECTRICAL APPLIANCE SECTOR IN CAPTURING THESE BENEFITS

Harnessing digital technology to develop new business models

China's urban dwellers have already shown a tremendous openness to sharing opportunities — but not across the board. In several product categories, attitudes and habits around hygiene impose serious barriers to picking up a sharing model — more so in China than in many Western societies. This is a challenge for clothing exchanges, but could also affect appliances and devices involving garment care, as well as food preparation and preservation.

This creates opportunities for engineers and marketers to come up with logistics and business models that put consumers at ease with used goods. And the innovation opportunity goes beyond overcoming this particular barrier. All in all, the most relevant innovations will be the ones that eliminate the various kinds of friction keeping an individual from participating in a sharing or pay-per-use (PPU) scheme. Convenience is a key factor here. Sharing a washing machine in the basement of a residential building, for example, becomes just a little more attractive if one does not have to look for coins in order to operate it, or if one receives a remote notification when the machine frees up.

This is true around the world, but in China in particular there is also the unique opportunity to use modern technology and new business models to keep some of the inherently circular behaviours that are still more or less present in society today, but risk being eroded. Bike-sharing, for example, taps into and preserves China's more traditional bike-based mobility. Sharing schemes for appliances and electronic devices could build on the communal attitudes that have defined much of Chinese society — and by applying technology and savvy marketing, they could retain or obtain appeal for its growing urban middle class.

Technology and innovation can also provide a boost to EoU solutions by tapping into the appetite of China's urban communities for online application and access models. In 2014, UNDP China and the internet giant, Baidu, teamed up through their Big Data Joint Laboratory to provide an app that links corporate and private end-users to legally certified e-waste disposal companies for safe disposal and recycling. Since its initial release, the app has grown to cover more products and cities, and the number of users and product searches has grown steadily.[481] With relatively little cost and effort, citizens can also tap into information about superior product designs, EoU options, and sharing opportunities. Alibaba is already adding some of this information to its vast consumer goods catalogue. Various online-to-offline (O2O) apps and websites are gaining traction in China's major cities, allowing individual citizens to make appointments for door-to-door collection of their discarded electrical and electronic appliances. Huishouge in Shenzhen, Wuhan and Tianjin, and Xiangjiaopi in Beijing are the best known, but there are countless other novel ventures that have great potential to deliver significant benefits in this space after further experimentation and fine-tuning. Leading pre-processors — on the lookout for feedstock — are most active here: Huishouge was developed by GEM and Xiangjiaopi by Huaxin.

Improving product design to enable circular business models

Currently, electronics and electrical appliances are often designed in a way that hinders repair and other activities that may require disassembly. One manufacturer found that a range of its small household appliances took a full six minutes to disassemble, with the three subassemblies worth recovering only becoming accessible in the last two minutes. Reasons for such design choices range from simple oversight to cost considerations to strategic intent. To increase the volume of devices that can be brought into a circular programme, and increase the margin made on each of these looped products or materials, a design process with a fuller remit than first use is necessary.

Design innovation plays a critical role in better EoU outcomes. To make a closed-loop model economically and technically feasible, designers must address durability, ability to repair and upgrade, ease of disassembly and parts recovery, ease of recycling materials, and the use of recycled and non-hazardous substances. Practical applications of these considerations include: standardising components such as power cords, displays or cameras across models, ranges and even brands (the latter possibly stimulated through industry standards); modularity and platform approaches when developing a product line or range; moving to closures and fastenings that ease disassembly (e.g. easy-access, clip-hold assembly instead of adhesives); matching as much as possible the projected failure rate of various parts and making the most vulnerable parts easily accessible; and making a clear distinction between wear-and-tear layers that will require an exchange, and durable cores that require mere cleaning or polishing. Built-in fault-tracking software – which identifies what parts of a returned device need to be replaced – could greatly facilitate the process of sorting used and returned devices, again improving margins.

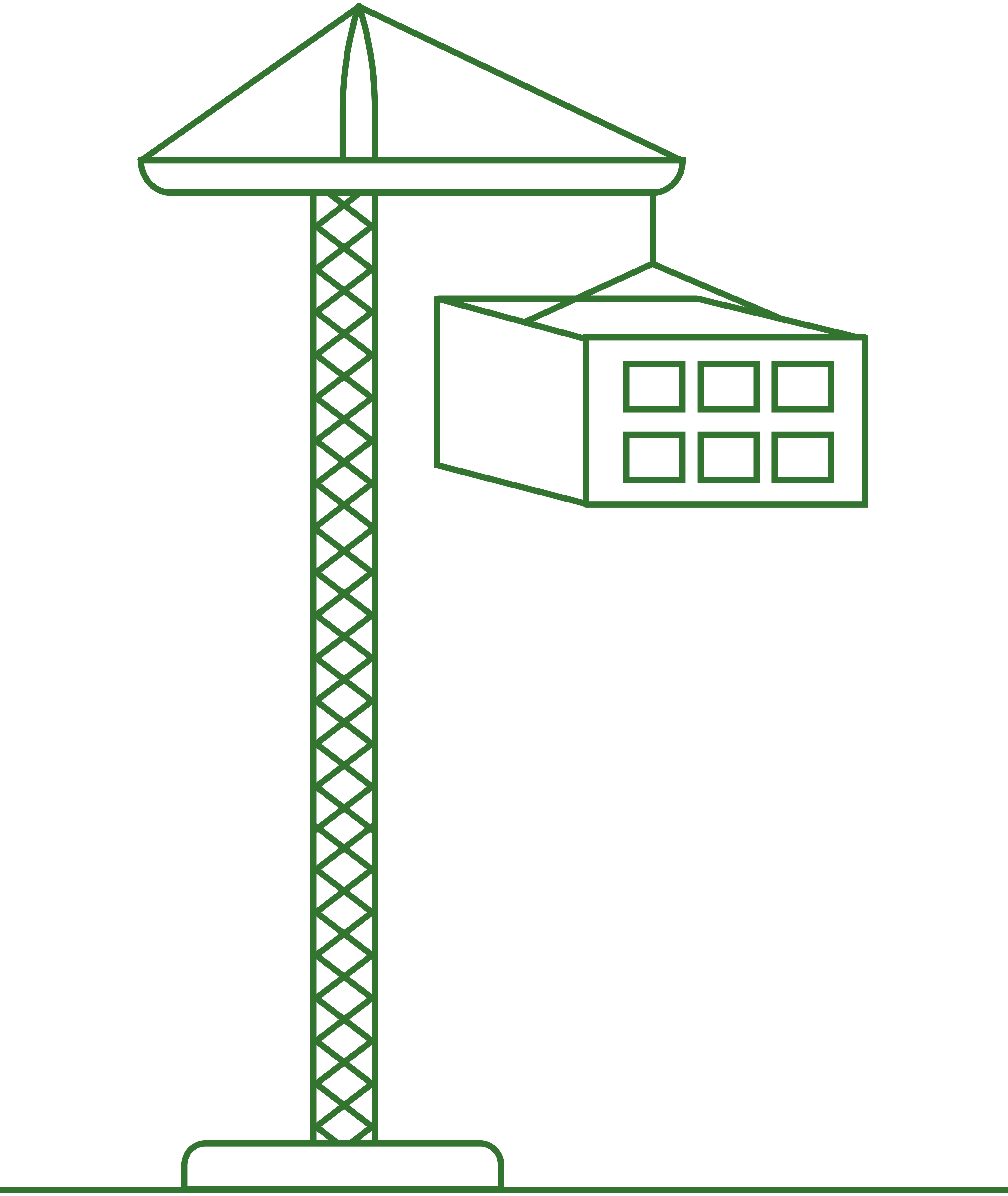
Policies to encourage such innovation are relatively new. However, companies like Huawei, Haier, and Xiaomi have already started to bring products onto the market that are easier to recycle, and if such organisations were to develop a complete, deliberate design-for-recycling/remanufacturing agenda, the bulk of their product portfolio could soon take on this 'secondary application' dimension.

Design plays an important role in making alternative business models more profitable. It is important to note that the business model must be designed or selected first, and product design entirely focused on it. For instance, devices for sharing or with multiple users not only need to be more robust and easier to clean and upgrade, but they may also need access, identification, and security features that single-owner products do not. Some of these design choices will involve trade-offs. Using a material, for instance, that is most suitable for recycling might result in a product less able to be repaired or remanufactured. In another example, designing a product for durability for the purposes of a sharing model might make it harder for uncertified repair shops to access its inner workings.

Building trust in secondary products and parts

To build a successful circular economy, businesses will require customers to overcome quality control concerns affecting post-consumer electronics and appliances. In order to avoid quality issues with secondary products or new products that include secondary parts, it is crucial that both process quality and output quality are clearly specified and monitored. At the moment, building trust in these products and parts is challenged by their different regulatory treatment. For example, refurbishment is allowed when the e-product is collected and treated as a whole, for example, a computer comes back onto the market as a computer. Further, once a product is pre-processed into different fractions, licensed pre-processors can, if they wish, send plastics, glass, and metal frames (e.g. the metal case of a TV or DVD player) for reuse for the same purpose instead of sending it for materials recycling. However, printed circuit boards (PCBs), considered hazardous, cannot be sent into part harvesting, remanufacturing, or reuse for the same purpose. Nevertheless, part harvesting from PCBs and PCB reuse still occur in the informal market.

Nevertheless, companies with strong remanufacturing/refurbishing track records, such as Caterpillar and Philips, have developed detailed inspection protocols and other internal quality control processes, and complement these with tracking and tracing throughout the secondary value chain. Both these practices contribute substantially to the growing confidence of markets and manufacturers in secondary products and parts.



4. HOW TO REALISE THE OPPORTUNITIES IN CITIES

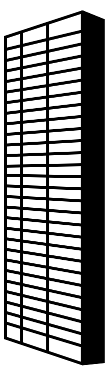
HOW TO REALISE THESE OPPORTUNITIES IN CITIES

CHINA'S CITIES HAVE A RANGE OF AMBITIONS THAT CIRCULAR ECONOMY SOLUTIONS CAN SUPPORT

China's cities range from service-oriented, world-class metropoles to production-focused prefecture conurbations. While circular economy opportunities exist for all types of cities, their size, growth stage, and industry focus make some sites more or less suited to different types of circular economy opportunities. Cities can be divided into archetypes based on some of the characteristics they share that are relevant for circular economy development. Figure 5 illustrates eight archetypes across three dimensions: GDP tier; growth level (above or below the national average); and industry focus (relative to the national average).

The characteristics of each archetype will lend themselves to particular circular economy opportunities. For instance, a developed megacity has the advantage of having a larger share of middle-class consumers whose demand for high-quality food could support organic urban and peri-urban farming; whose exposure to digital technologies could allow digitally enabled sharing and pay-per-use (PPU) schemes; and who are likely to provide sufficient stocks of secondary textiles and electronic products to enable the upscaling of collection and closed-loop activities. On the other hand, a city under development and expansion has a great opportunity to leapfrog into urban design based on circular economy principles, with greater asset utilisation and more sharing schemes based on advanced technologies. The mobility system could be designed from the outset to be suitable for electric, shared, and multi-modal mobility (e.g. Transit-Oriented Design, (see Box 6, p.62) cycling paths, and EV charging points). A city generating most of its economic value from manufacturing industries could invest in more efficient production measures and develop a strong base of remanufacturing, thereby upgrading and de-risking its existing linear industries.

FIGURE 5: CITY ARCHETYPE



		GROWTH LEVEL	ARCHETYPE
TERTIARY	TIER 1+2	LOW	World-class metropoles with well-defined economic base
		HIGH	Regional champions driven by focused innovation e.g. IT, medicine
	TIER 3+4	HIGH	Prefectures catered to external services, e.g tourism
SECONDARY	TIER 1+2	LOW	Regional economies with growth limited by structural bottlenecks
		HIGH	Regional champions driven by general technology upgrade[1] and/or rapid logistics developements
	TIER 3+4	LOW	Prefectures with growth limited by structural bottlenecks
		HIGH	Prefectures driven by concentrated growth in innovation related product manufacturing[2]

1 e.g. aerospace, new materials
2 e.g. wafers, precision machinery

For example, Beijing is a Tier 1 city, with a growth rate of 6.7% (in 2016), and its economic activities are predominantly service-oriented. As a world-class metropole, Beijing is a mature city with an established infrastructure, which aims to attract talent by providing an affordable and functional living environment. As such, the circular economy opportunities here could be focused around building up transport infrastructure and refurbishing the built environment along circular economy principles. Such opportunities are already being explored in the city as seen in the plethora of office-sharing, bike-sharing and even car-sharing schemes that have sprung up; the increasing attention on bike-friendly urban planning; and even signs of an increase in collection activities and secondary markets for textiles and electronics.

Another example, Hangzhou, a city famous for its tourism and good standard of living, is becoming a centre for IT, especially Big Data and cloud services. Since it has a well-developed service industry, it could decouple its growth from negative environmental externalities by stimulating the take-up of key technologies such as the digital tracking of products and materials to support relevant circular economy schemes. The city has put much effort into supporting innovation and entrepreneurship (e.g. co-hosting training projects with Alibaba)[482] in the IT field. It has also utilised these resources in areas such as traffic management to benefit its citizens. As a consequence, in 2016, the IT industry contributed 24% of the city's GDP.[483]

POLICY INTERVENTIONS CAN HELP EASE BARRIERS TO REALISING CIRCULAR ECONOMY OPPORTUNITIES

Despite their sizeable benefits, the implementation of circular economy opportunities in China might be hindered by a variety of barriers. These fall into four main categories: economic, market failures, regulatory failures, and societal factors, as set out in the Ellen MacArthur Foundation report *Delivering the circular economy*.[484]

The significance of these barriers varies across the three urban systems and two industry sectors considered in this report. This study has carried out an initial prioritisation analysis based on industry interviews and desk research, the result of which is presented in the form of a heat map (Table 2, p.124). The analysis also provides some current government-led initiatives in China to overcome barriers as well as examples of similar interventions in other countries.

The *Delivering the circular economy* report also lists the six major types of intervention available to policymakers at national, regional, and city level to overcome these barriers: regulatory frameworks, fiscal frameworks, public procurement and infrastructure investment, business support schemes, collaboration platforms, and education, information and awareness building. Policymakers can draw inspiration from national and international success stories to set direction and incentives creating the right enabling conditions for a circular economy transition.

Economic barriers

Previous research has shown that circular approaches often have a positive contribution to a company's bottom line and a country's economic position and competitiveness.[485] However, economic concerns come into play in cases when the circular opportunity is not yet profitable due to factors such as scalability in its early stage – something true for any innovation – and lack of access to suitable technology and capital. It should be noted that a lack of profitability of a circular economy opportunity often has an underlying cause such as unpriced externalities.

Profitability could be a challenge in some cases, especially when a circular business venture is in its early stages, when potentially neither the market nor the relevant technology is mature at scale.[486] For example, some organic waste-processing plants in China's cities currently struggle due to sub-optimal quality and quantity of feedstock and undesirable output. In the short term, government subsidies could keep their operations running, but more efforts on technological advancement to improve the economics of both the feedstock and output would be needed to achieve financial independence in the long run.

Lack of access to capital and uncertain payback times can be a hindrance when trying to deploy circular economy practices at scale. For example, for green buildings and 3D-printed houses, there is a time lag between investments (e.g. in energy efficiency) and the benefits and split incentives (e.g. the benefits of energy-saving investments made by the landlord accrue to tenants). High initial investments are often barriers to property developers and builders. Additionally, for recycling and other closed-loop schemes to work, new processing infrastructure would be required, which would need access to sufficient capital at the early stage. This is especially problematic when the upgrading of factories doesn't fit the natural investment cycle and if the payback timeframe doesn't match the industry timeframe.[487]

There are a variety of potential measures that could overcome these barriers. For example, to secure the necessary capital in the construction sector, the central and regional governments could promote and establish information platforms and regulations for public-private partnership (PPP). In fact, such work has been taking place in China since 2014[488] and the Ministry of Finance and the NDRC have both published operational and contract guidelines for PPPs.[489] For example, the China PPP Service Platform[490] provides a project database, policy information, and successful case studies to attract investors.

Another measure is green procurement, such as the policy implemented by the Beijing municipality to support the prefabrication of buildings. The Beijing municipal government requires all new government-invested buildings, public affordable housing projects, and large commodity residential projects to use prefabricated components.[491] Additional economic incentives, such as tax refunds and subsidies, have also been tested. For example, the government of Shandong has provided value-added tax refunds to manufacturers of prefabricated components, cost reimbursements for the use of prefabricated walls, subsidies for corporates to invest in research and development, and reductions in quality assurance deposits for prefabricated building construction projects.[492]

When it comes to investing in energy efficiency, the EU aims to use public money to reduce the cost of capital expenditure for the private sector. They do this by providing loans with longer maturities or lower collateral requirements. Such an approach advocates making the energy-efficiency market fully investable, targeting public funds towards vulnerable consumers or specific market failures[493] – and could be implemented in China. Indeed, an important mechanism to unlock capital for energy-efficiency measures already exists in the country's Energy Service Companies (ESCos) or Energy Management Companies (EMCos). In China, these companies provide a 'full service' model, which identifies, designs, finances, and oversees the installation of energy-efficiency projects, and is compensated by receiving a share of the resulting energy savings. It has been suggested that as the EMCo industry grows in China and as banking sector reform continues, EMCos will increasingly be able to obtain financing directly from local banks. A similar mechanism is the Energy Performance Contract (EPC), which focuses on the energy intensity of buildings rather than their energy consumption. In Shenzhen, when an EPC project reduces the energy intensity of a public building the city does not reduce the building's energy budget, but keeps it the same to cover both the energy bills and the payments for the EPC. This model is attractive to the owner of the building and the private contractor, and the shared risk means that deeper energy savings can be pursued, making such an approach attractive to providers of external finance.[494]

Market failures

Unpriced externalities and transaction costs are two cross-cutting market failures that hinder the scaling up of circular businesses. Other market failures can include split incentives, imperfect information, insufficient public goods or infrastructure, and insufficient competition.

Unpriced negative externalities can be a barrier to circular economy transitions in any sector and anywhere along the value chain, from the sourcing of cheap raw materials to landfilling at very reduced costs. The results of this approach are visible, for example, in China's textile manufacturing chain, which, in the past, has largely not accounted for its dramatic effect on local surface waters. Similarly, the consequences of the over-use of synthetic fertilisers in conventional farming systems, the global warming impacts of vehicles burning fossil fuels, and the methane emissions and toxic leachate from landfill sites are not currently priced. This lack of prices means that some of the benefits of circular practices are unappreciated by the market, as it favours the apparently cheaper linear system without acknowledging its inherently higher mid- to long-term environmental and societal costs.

One of the initiatives aiming to tackle this problem is China's Water Ten Plan, which bundles together various regulations and policies designed to reduce negative externalities in the country's textiles production sector, along with addressing nine other major polluting industries. Another way to even the playing field for circular models is to put a price on externalities through, for example, carbon pricing schemes which have been emerging all round the world over the last decade.[495] Such an approach can be coupled with a reduction in subsidies for practices that incur environmental costs. At the city level, the fast-growing number of low-emission zones and other access regulations introduced by city planners around the world aim to reduce externalities by factoring them into the cost of using vehicles run on fossil fuels.[496] Beyond policy interventions, companies could take account of shadow prices for externalities in their internal decision-making processes. According to the Carbon Disclosure Project (CDP), 435 companies with business activities, ranging from toolmaking to mining, reported using an internal carbon price in 2015. Such an approach can incentivise carbon reduction measures and investments, in areas such as energy efficiency and renewable energy, which in turn help to reduce the risk of higher carbon prices or other forms of emission reduction regulations in future.[497]

Transaction costs in the form of finding and bargaining with customers or suppliers of secondary materials are often caused by information relevant to circular opportunities not being easily accessible. For example, the formal electronics processing industries have difficulties ensuring sufficient feedstock in a B2C model even in big cities due to competition from the informal sector and low public awareness of available recollection channels.[498] In this case, innovative and effective channels need to be established for formal electronics and electrical appliance recycling to be successful. Inspiration could be drawn from digital-sharing platforms, such as the Chinese property-sharing platform Tujia, which do an effective job of matching supply and demand.

To bridge the gap more generally, both the government and the private sector could take the lead in establishing platforms to connect the providers and buyers of secondary materials. For instance, the Xinxiang municipality supports the establishment of local circular economy industrial development by actively attracting businesses with complementary material input and output flows to the existing industries.[499] Similar initiatives also take place abroad, one such case being the Danish Industrial Symbiosis Programme, which support private companies in the exchange of by-products through creating transparency on available flows of materials.[500] Shanghai city has taken another angle by establishing a multi-party, multi-channel approach towards the 'urban mining' of e-waste by integrating online platforms and offline logistics. In addition to policy-led initiatives, reverse logistics businesses could also explore different channels for collection, leveraging online and offline platforms.

Regulatory failures

Inadequately defined legal frameworks and unintended consequences of existing regulations could also hamper circular practices. Other potential regulatory failures are poorly defined targets and objectives, along with implementation and enforcement failures.

Unintended consequences of existing regulations could hamper some circular economy levers. For example, food safety regulations that protect public health from unsafe practices in the food supply chain could also prevent the use of by-products or food waste that would increase the circulation of nutrients in the food system. While guaranteeing the safety of food should be the highest priority for the supply chain and must not be compromised, efforts can still be made to close nutrient loops where possible.

A similar problem is also visible in the remanufacturing of automotive parts. China's current policy for the sector prohibits remanufactured parts to be used for warranty replacements and also imposes restrictions on the import of remanufactured parts.[501] Government support would be essential, therefore, to realise the potential of the car remanufacture industry, which could be in an increasingly high demand in the coming years.[502] As a rising number of global remanufacturers are interested in setting up facilities in China, the industry would greatly benefit from an easing of restrictions on using remanufactured parts during the warranty period, as well as relaxing import policies. Safety concerns over using remanufactured parts have receded as technologies have advanced and manufacturers have gained experience. For example, 80–85% of raw materials at Volvo are reused in remanufacturing.[503] Similarly, Renault has been remanufacturing and using parts in repair activities since 1949 and has been steadily diversifying its output to include injection pumps (1989), gearboxes (2003), injectors (2010), and turbo-compressors (2013).[504]

Inadequately defined legal frameworks sometimes pose a challenge when it comes to turning 'waste' into a resource. In many sectors, it is challenging to create a holistic policy and regulatory system, and to couple it with existing action plans because waste management involves many actors across the collection, transportation, and reutilisation phases. The definition and standard of 'waste' can also vary between different actors. This challenge can pose a significant barrier, for example in reusing construction and demolition waste.[505]

A robust and consistent regulatory system for landfill management; action plans that cover the waste value chain; clear waste classification; and instructions and standards on processing could help address this barrier. China's National Sword campaign is an example of such an enabling policy intervention. While the campaign's efforts to improve the quality of imported feedstock have been closely followed by the international community, the campaign also aims to rule out illegal processors and substandard recycling facilities inside its territory.[506] In Europe, the European Commission aims to facilitate the return of 'waste' materials into the economy through the introduction of so-called end-of-waste criteria. These criteria specify the exact steps that these materials have to undergo in order to cease to be classified as waste. So far, such criteria have been developed for scrap iron, steel, aluminium and copper, and glass cullet.[507] Such standards might be developed by industry too. Take the example of compost, where contaminants such as heavy metals might severely limit its possible applications and, therefore, its market value. Policymakers in California and Ontario have developed standards for its use. In the UK, the Publicly Available Specification 100 (BSI PAS 100) for composted materials was developed by the Waste and Resources Action Programme (WRAP), a non-profit organisation, together with the UK's Association for Organics Recycling.[508]

Societal factors

Even in the absence of other barriers, societal factors could present additional challenges to a circular economy transition. These can take the form of customs and habits of citizens and business people that make adoption of certain circular economy opportunities difficult, and a lack of capabilities and skills to take these opportunities. An example of the latter barrier can be seen in the built environment, where the disruptive technologies that enable circular practices, such as durable and flexible design, and industrialised processes of construction, could be applied much more if the capabilities and skills necessary to do so were common throughout the industry. More public and private funding of training programmes for architects, engineers, construction workers, and others along the value chain would help in this endeavour.

CUSTOM AND HABIT

Opportunities that require a change in mindset or behaviour can take longer to mature, even if technology has advanced to address public concerns. For example, in the food sector, addressing the mindsets of farmers to adopt more regenerative production for the long-term fertility of the soil, as well as the mindsets of consumers to support such practices could help accelerate such a transition. People's acceptance of sharing rather than owning products and assets, and their trust in secondary products, also takes time to be established. Private sector digital-sharing platforms have identified new mechanisms to create the necessary trust, with companies such as

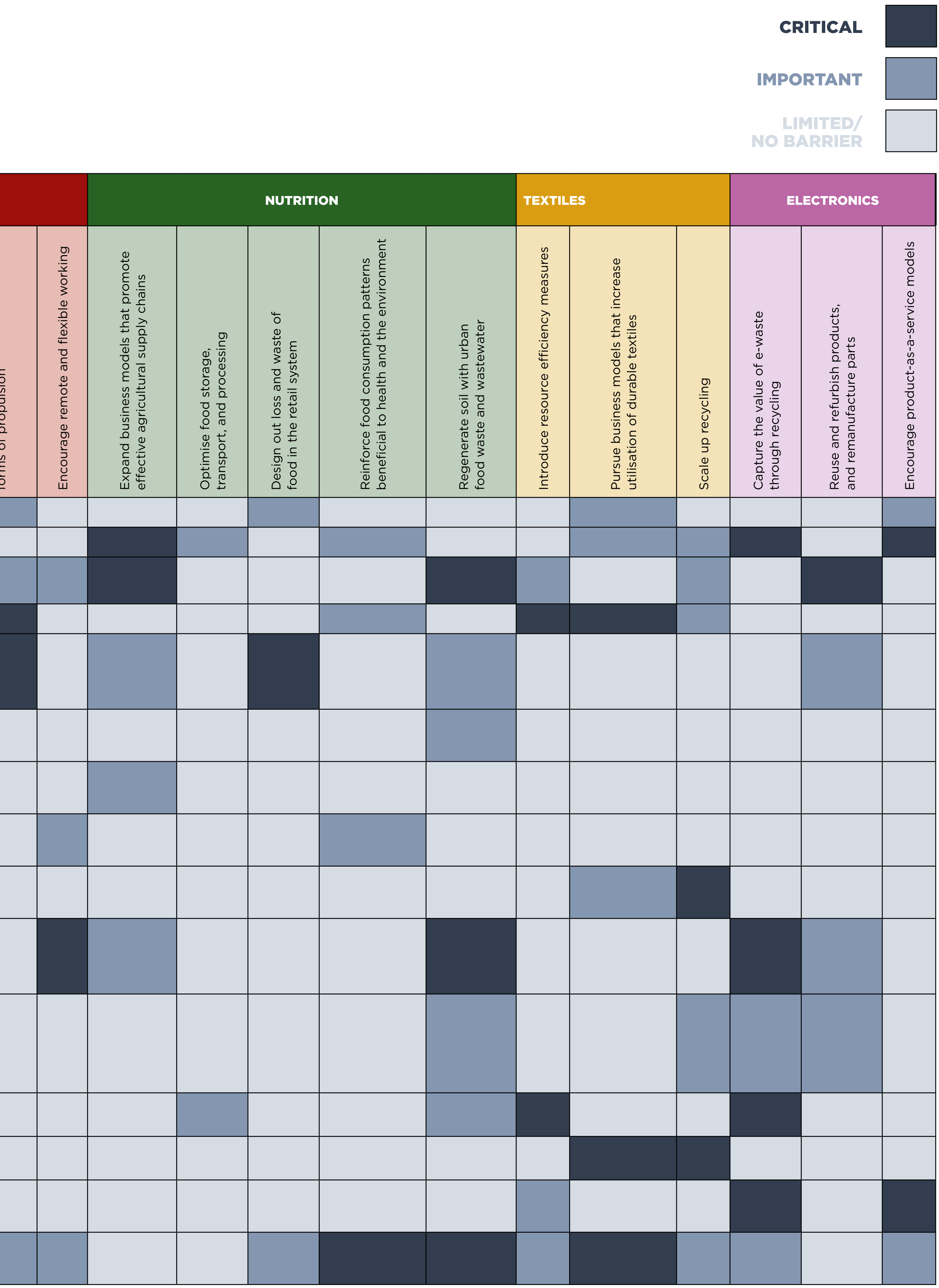
Tujia now providing a review opportunity on both the supply and the demand side. While Tujia's review process is still facing early stage business challenges, platforms with a longer history such as eBay and Airbnb have demonstrated that the process can be lifted to a level where trust is no longer a barrier to participation. Governments can influence retailers, service crews, and other first-line consumer contacts to guide and reinforce behaviour. For instance, the French government has issued a decree making it compulsory for automotive repair shops to inform customers that they have the choice to use remanufactured parts, putting forward arguments including waste reduction, reduced resource use, and reduced price for the end-user.[509]

Another example is the view in China of car ownership as a social status symbol, which could deter the public from choosing public transportation.[510] To overcome this barrier, the circular mobility system could use digital technology to make public transport more appealing and convenient to use, so encouraging urban residents to choose it over private modes of transport. Cities could also play a role to make multi-modal and shared mobility preferable options for the public. The city of Yichang has beautified the pedestrian environment and digitalised the public transport information for easier passenger access, which has had a great effect and the people-centric, multi-modal public mobility has thus gained popularity. (See Case Study 1, p.63.)

TABLE 2: HEAT MAP OF THE PRIORITISATION OF CIRCULAR ECONOMY OPPORTUNITIES IN CHINA

This heat map shows an initial prioritisation analysis of circular economy opportunities in China, based on industry interviews and desk research. The extent to which specific barriers hinder the circular economy uptake has been indicated at three levels, distinguished by the shading of the cells in this table, ranging from critical, through important, to limited/no barrier.

BARRIER FRAMEWORK AND DEFINITIONS		BUILT ENVIRONMENT						MOBILITY			
BARRIER TYPE	BARRIER	Design for longevity	Industrialise construction processes	Share space to increase asset utilisation	Improve energy efficiency through 'green buildings'	Enhance productivity with 'smart buildings'	Scale up reuse and recycling of construction and demolition waste	Facilitate multi-modal shared mobility	Scale up remanufacture and use more recycled materials	Design vehicles to fit a circular mobility	Scale up zero-emission forms of propulsion
ECONOMIC	Profitability	Limited	Critical	Important	Limited	Limited	Important	Limited	Limited	Limited	Important
	Capital	Important	Limited	Limited	Important	Critical	Limited	Important	Important	Important	Limited
	Technology	Limited	Important	Limited	Important	Important	Limited	Limited	Limited	Important	Important
MARKET FAILURES	Externalities	Limited	Limited	Limited	Important	Important	Important	Important	Important	Limited	Critical
	Insufficient public goods/ infrastructure	Limited	Limited	Limited	Limited	Limited	Important	Important	Limited	Limited	Critical
	Insufficient competition	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited
	Imperfect information	Limited	Limited	Limited	Limited	Limited	Critical	Limited	Limited	Limited	Limited
	Split incentives	Important	Limited	Important	Important	Limited	Limited	Limited	Important	Important	Limited
	Transaction costs	Limited	Limited	Limited	Limited	Limited	Important	Limited	Limited	Limited	Limited
REGULATORY FAILURES	Inadequately defined legal frameworks	Limited	Limited	Critical	Limited	Limited	Critical	Important	Critical	Limited	Limited
	Poorly defined targets and objectives	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited
	Implementation and enforcement failures	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Important	Limited	Limited
	Unintended consequences	Critical	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited
SOCIETAL FACTORS	Capabilities and skills	Critical	Critical	Limited	Important	Important	Important	Important	Limited	Limited	Limited
	Custom and habit	Limited	Limited	Limited	Limited	Important	Limited	Critical	Limited	Important	Important


CRITICAL
IMPORTANT
LIMITED/ NO BARRIER
NUTRITION
TEXTILES
ELECTRONICS
forms of propulsion
Encourage remote and flexible working
Expand business models that promote effective agricultural supply chains
Optimise food storage, transport, and processing
Design out loss and waste of food in the retail system
Reinforce food consumption patterns beneficial to health and the environment
Regenerate soil with urban food waste and wastewater
Introduce resource efficiency measures
Pursue business models that increase utilisation of durable textiles
Scale up recycling
Capture the value of e-waste through recycling
Reuse and refurbish products, and remanufacture parts
Encourage product-as-a-service models

POLICYMAKERS AND BUSINESSES EACH HAVE AN IMPORTANT ROLE IN REALISING CIRCULAR ECONOMY OPPORTUNITIES

China has proven that it can develop leadership in new low-carbon technologies fast, with cases in point being the rapid upscaling of electric vehicles and renewable energy. Given their scale and pace of development, as well as the many stakeholders and wide pool of talents on offer, China's cities could become powerhouses in an accelerated transition towards the circular economy. Achieving such a circular vision would require commitment, innovative thinking, and collaboration from actors across the public and private spheres. Policymakers at various levels could set the direction and establish incentives to create the right enabling conditions; business owners could leverage circular economy principles to encourage innovation; and academia, think tanks, and industry associations could conduct research and disseminate knowledge to raise awareness.

Policymakers

Policymakers at the national, regional, and city levels could leverage their legislative powers and play a leading role in establishing the policy and financial framework to enable businesses to achieve the circular economy vision. Six major intervention types could contribute to lifting the main barriers to circular economy implementation:

- **Regulatory frameworks:** government (sector) strategy and associated targets on resource productivity and circular economy; product regulation, including design, extended warranties, and product passports; waste regulations, including collection and treatment standards and targets, the definition of waste, extended producer responsibility, and take-back systems; industry, consumer, competition, and trade regulations (e.g. on food safety); accounting, reporting, and financial regulations (including accounting for natural capital and resources)
- **Fiscal frameworks:** VAT or excise duty reductions for circular products and services; tax shift from labour to resources
- **Public procurement and public investment in infrastructure:** green public procurement to integrate green goals in the policies. Criteria include recyclability, product lifespan, total cost of ownership, etc. [511]
- **Business support schemes:** financial support to business (e.g. direct subsidies, provision of capital, financial guarantees); technical support, advisory bodies, training, and demonstration of best practices
- **Collaboration platforms:** public-private partnerships with business at national, regional, and city level; encouragement of voluntary industry collaboration platforms as well as cross-value chain, cross-sectoral initiatives and information sharing; joint R&D programmes
- **Education, information, and awareness:** integration of circular economy/systems thinking into school and university curricula; public communication and information campaigns

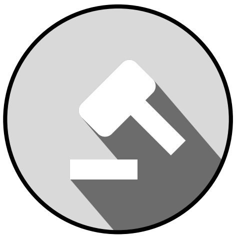
The six intervention types have been illustrated with examples in Figure 6.

FIGURE 6: SIX INTERVENTION TYPES FOR POLICYMAKERS TO ACHIEVE A CIRCULAR ECONOMY

PUBLIC PROCUREMENT & INFRASTRUCTURE

Beijing has a green public procurement scheme to support prefab buildings.

REGULATORY FRAMEWORKS



Suzhou city mandated restaurants to recollect their organic waste for treatment.

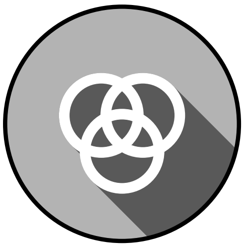
FISCAL FRAMEWORKS

Shanghai city granted Yuanyuan a textile recycling company tax reduction.

INFORMATION & AWARENESS

Shanghai Selot hosted more than 2,000 educational events to raise public awareness on sorting e-waste from municipal waste.

COLLABORATION PLATFORM



The Ministry of Finance established China Public Private Partnership Center to support and promote PPP projects.

BUSINESS SUPPORT PLATFORMS

China central government provided subsidies for e-waste recycling industries.

Source: Ellen MacArthur Foundation, *Delivering the circular economy: a toolkit for policymakers*, (2015)

China's central government has been showing its commitment to the implementation of a circular economy by actively developing the legislative framework and guidelines while setting binding targets at a national level,[512] which are then adapted to the provincial and municipal scale for implementation. In China, circular economy implementation is led by the NDRC, which provides high-level guidance and capacity building for cities of different sizes and industrial characteristics to adapt national policy and to develop their own circular economy models.

An important function of the central governments is the creation of platforms for dialogue, cooperation, and public awareness across industries, along the value chains, and with contributions from academia, think tanks, and industry associations. For instance, the China Association of Circular Economy is a great example of such a cross-sector platform, and the China Resource Recycling Association has specialised subdivisions focusing on individual industries such as e-waste. Central governments could also push for the integration of circular economy concepts into the curricula, promote capacity building of designers and engineers, and take the lead in public communication and information campaigns to encourage societal acceptance of circular businesses models (i.e.. shared mobility and high-end garment rental services).

Provincial and municipal governments are in a prime position to aid the emergence of circular business activities. Alongside public procurement, public investments in circular economy opportunities, and other forms of financial support (e.g. for R&D), they can also offer technical support to businesses in the form of advisory bodies, industry training, and demonstration of best practices. They can further aid the transition by setting up the appropriate collection and treatment infrastructure, in close collaboration with business, to inform the continuous improvement of reverse cycles.

Businesses

Circular economy approaches work at all scales, with the diversity of solutions making the economy more resilient. Businesses, big and small, private and state-owned, are central in the transition from linear to circular. With sufficient support from government, and the introduction of a circular economy framework for innovation, circular businesses could discover new opportunities for revenue and cost saving. Entrepreneurs can thrive in China's cities thanks to price-sensitive consumers, digitalisation, and high material and population density. This environment allows innovators to quickly find niches that established businesses have not yet filled.

Novel technology, circular design, and business model innovation enable the private sector to provide people with healthier and more convenient options with fewer environmental and societal externalities. Such design elements include design for disassembly, recoverability, modularity, and flexibility; and business models include access-over-ownership and product-as-a-service. Business-driven digital solutions are important enablers for the transition from linear to circular. Examples include the consumer electronics recycling platforms of Aihuishou and Youdemai, and Alibaba's thriving online marketplace for any secondary goods or materials in the industrial space,[513] as well as Taobao's C2C consumer product online market Xianyu. In parallel, social platforms such as WeChat enable dozens of start-ups, including Aobag and Bengege in the secondary goods and materials market, to find or help create a match of buyer and at little or no cost.[514] As well as offering a trading space for secondary products, digital platforms have also been significant enabling factors in the uptake of bike-sharing (e.g. Mobike) and property-sharing (e.g. Tujia).

Corporate communication and public awareness campaigns can also create the necessary public buy-in from customers by encouraging them to actively demand higher product quality and safety, establishing trust in secondary products and materials, and helping users accept and appreciate access-over-ownership models. Interface's Net-Works® programme is a good example of this – it collects discarded fishing nets and makes them into carpets, raising public awareness about the high levels of plastic pollution in the ocean.[515]

Academia, think tanks, and industry associations

For the circular economy ecosystem to flourish, it is vital that current and future designers, engineers, strategists, and marketers are equipped with the capabilities and skills needed to develop successful circular economy solutions and to think with a systems perspective. Academia, from school level onwards, plays a key role in inspiring the next generation in this direction. As well as addressing research gaps, another role of academics is to advise policymakers: the Tsinghua University's Joint Research Center for Industry of China's Circular Economy, for instance, was founded in 2009 to meet the central government's demand for technology and policy strategy support.[516] Moreover, industry associations, think tanks, and other multi-stakeholder platforms are important vehicles to allow active stakeholders to reflect upon and learn from the collective experiences, data, and progress of circular economy initiatives.

Collaboration

No one single party can achieve a circular economy transition alone. Since they overcome silos, collaborations across various spheres and sectors are crucial to realising the circular economy opportunities discussed in this report. The main types of collaboration are:

- **Public-private partnerships (PPPs).** At national, regional, and city levels, PPPs are a powerful measure to realise large-scale projects as, together, the parties involved bring a potent combination of skills, perspectives, and financing. China has been very active in encouraging and exploring various forms of PPPs. For example, China's PPP Service Platform not only provides a way for public and private investors to connect to projects, but also collects and shares case studies so all parties can learn from the experiences of others. One example of a PPP in action at the city level is Hangzhou's Metro Line 1 which is a joint venture between Hangzhou Metro Group and the Hong Kong-based MTR corporation under a 25-year PPP.[517]

- **Policymakers and businesses.** Policies enabling a circular economy could be best implemented if carried out in consultation with the private sector. For example, Cainiao has been engaging with the government to co-develop standards for plastic packaging used by courier services.

- **Cross-value chain initiatives.** These have the ability to bring together key stakeholders that would not normally collaborate to realise practical yet systemic aims. For example, the New Plastics Economy Initiative (NPEC), led by the Ellen MacArthur Foundation, brings together global consumer goods companies, retailers, plastic producers and packaging manufacturers, cities and businesses involved in collection, sorting and reprocessing. The initiative's aim is to move the plastics value chain into a positive spiral of value capture, stronger economics, and better environmental outcomes.[518]

- **City networks.** These can be established to share reverse logistics and recycling industry capacity. Smaller cities may not have enough secondary material stock (e.g. electrical appliances and electronics) to warrant their own processing plants and could, therefore, leverage similar schemes in adjacent larger cities (e.g. Sangde, an e-waste recycling company in Miluo collects feedstock from 14 nearby cities).[519] Moreover, experiences from implementing circular economy opportunities could also be shared between cities with a similar industry focus and/or development stage, as was the aim of the NDRC's 60 case studies document.[520]

- **Cross-government ministries.** It takes joint efforts from various departments at national or municipal level to successfully carry out circular economy plans citywide. Take the example of e-waste collection in Shanghai: the DRC and the Commission of Commerce carries out the national policy and oversees e-waste recycling; the finance department secures and distributes the funds from the central government; and the Ministry of Environmental Protection monitors the waste and emissions during the recycling process.[521]

- **International.** Chinese and foreign cities, as well as international organisations, could learn from each other's experiences, technologies, and know-how. This is especially relevant nowadays as Premier Li Keqiang's visit to Europe solidified China's and Europe's commitment to collaborate on the transition to the circular economy. A great example of such collaboration happening on the ground is the district of Kunming Chenggong's pilot Transit Oriented Development urban planning project was of a joint effort between the municipality, local developers, and international urban mobility experts from Calthorpe Associates[i] and the Energy Foundation.[522]

Ultimately, China and other countries aiming to accelerate the circular transition need an even better integration of national, regional, and sectoral policy programmes, coordinated by a unified circular economy framework and clear priorities, to create the right incentives and enabling conditions for circular businesses to thrive. Multi-level, public-private, and cross-industry collaboration is required to achieve system-level change. Local, national, and international lighthouse projects and best practices could help make ambitious targets to this end tangible and actionable. Due to their innovative power, multiplicity of stakeholders, and sheer scale, China's cities have the opportunity to take centre stage in this transition and to become beacons of the circular economy at home and abroad.

i US-based regional design, urban plan, and architecture firm.

TECHNICAL APPENDIX

CIRCULAR ECONOMY OPPORTUNITIES PRIORITISATION

This appendix explains the major underlying assumptions and modelling methodology for the impact assessment. It presents an overview of the focus areas and opportunity selection. It then uses two of the five focus areas – mobility and nutrition – to illustrate the methodology used to quantify impact in the report.

Focus areas

The methodology for the focus area selection is derived from the Ellen MacArthur Foundation report *Delivering the circular economy*.[523] In line with this, the prioritisation is done across two dimensions: the role in the national economy; and the circularity potential. In the context of the Chinese economy, the role in the national economy parameter was calculated as a weighted aggregate of employment and the contribution to gross value added (GVA) for each sector (see Table 3). The circularity potential was calculated based on the direct materials consumption (DMC) and the amount of recycled content (percentage of input materials that is recycled). While these are only two indicators of circularity potential, they highlight two different dimensions – namely, resource intensity and degree of looping (illustrating one particular form of looping). Moreover, they benefit from the availability of a dataset with good internal (i.e.. between the sectors) consistency. We therefore consider them adequate indicators for this selection exercise.

Opportunities

For each sector, a long list of circular economy opportunities was identified based on the Foundation's previous studies such as *Circular Economy in India: rethinking growth for long-term prosperity* and the ReSOLVE framework developed in *Growth Within: a circular economy vision for a competitive Europe*. Opportunities were then shortlisted by relevance and applicability to the Chinese urban context. Selected opportunities were then prioritised based on two dimensions: potential impact, and feasibility of implementation. The opportunity selection was confirmed with industry experts.

TABLE 3: FOR EACH SECTOR, THE SCOPE WAS SET USING THE GLOBAL TRADE ANALYSIS PROJECT (GTAP) CLASSIFICATIONS

FOCUS AREA	COMPONENTS	GTAP CODE	GTAP DETAILS
BUILT ENVIRONMENT	Construction	cns	Construction: building houses (factories, offices, and roads excluded)
	Real Estate & Renting	obs	Other business services: real estate, renting, and business activities
MOBILITY	Transport/ Transport Infrastructure	otp	Other transport: road, rail **(Only for passenger mobility not freight)**
	Transport Equipment	otn	Other transport equipment: manufacture of other transport equipment **(Only for passenger mobility not freight)**
	Motor Vehicles	mvh	Motor vehicles and parts: cars, lorries, trailers, and semi-trailers **(Only for passenger mobility not freight)**
NUTRITION	Agriculture	pdr	Paddy rice
		wht	Wheat
		gro	Other grains
		v_f	Vegetables & fruits
		osd	Oil seeds
		ctl	Cattle
		oap	Other animal products
		rmk	Raw milk
	Food & Beverages	cmt	Cattle meat
		omt	Other meat
		vol	Vegetable oils
		pcr	Processed rice
		ofd	Other food
TEXTILES	Textiles & Apparel	tex, wap	Wearing apparel: clothing, dressing and dyeing of fur Textiles: textiles & man-made fibres
ELECTRONICS	Electronics	ele	Electronic equipment: office, accounting & computing machinery, radio, television, & communication equipment & apparatus
	Other Machinery	ome	Other machinery & equipment: electrical machinery and apparatus n.e.c., medical, precision & optical instruments, watches & clocks

IMPACT ASSESSMENT ACROSS FOCUS AREAS

Impact quantification

To illustrate the impact quantification at the city level, Figures A1 and A2 illustrate examples of the modelling approaches we found useful in our analysis: a map and a driver tree, respectively. The modelling was calibrated to the Chinese urban context by applying the urbanisation rate to national statistics.

The impact of these opportunities was quantified by looking at the total cost of access (TCA). TCA is made up of cash-out costs and externality costs. Cash-out costs exclude governmental subsidies and incremental capital expenditure (the additional investments needed to move to the circular economy scenario). Externality costs represent the economic costs, such as lost earnings and healthcare expenditures, associated with, for example, emissions of greenhouse gases and of particulate matter with a diameter of 2.5 micrometres (PM2.5) and 10 micrometres (PM10).

The choice to exclude from the analysis the incremental capital expenditure (capex) needed to put the opportunities in place was made to avoid obscuring the relative benefits of opportunities within a sector and across sectors. There is a first set of opportunities that comes with little or no investment and hence the net benefits shown in the chapters are reflective of an actual programme. These opportunities include efforts that aim to modify behaviours, such as programmes and campaigns for healthier eating and for less plate waste. Their cost has been outlined in the nutrition chapter. There are those with moderate and quite clearly delineated investment requirements. Many of the efforts to build better end-of-life pathways fall into this category. Processing food waste from a municipal waste stream, for example, requires an investment of about CNY 113 million (USD 18 million) for a digester with a capacity of 100,000 tonnes per year. Finally, there are investment-heavy interventions. As might be expected, these can mainly be found in the sectors that yield the biggest benefits – mobility and built environment. Achieving an integrated mobility system, for example, might incur such costs as CNY 40 million (USD 6.4 million) per kilometre for light rail transit, whereas putting in the necessary charging infrastructure for electric vehicles could come with a price tag of around CNY 70,000 (USD 11,235) per fast-charging station. Any investment decision here would require a more granular perspective on the opportunity before moving ahead with the inherently complex assessment process. The good news is that all of these elements, even relatively new developments, such as electric vehicles, have been costed out in quite some detail in the available literature.

Labour costs are included in cash-out costs, measured at retail values. For the circular economy scenarios, there will be a shift in labour intensity (a change from primary to secondary manufacturing and a shift from product-sale to service-based model), but it is not clear yet how, and how fast labour intensity would develop. Therefore, we have not made assumptions on this aspect in this report. For a more detailed discussion of labour effects, please refer to the Ellen MacArthur Foundation's report *Growth Within*.[524]

The analysis focuses on the urban context. On the one hand, the prioritised opportunities look at measures applicable to the urban context, therefore excluding most production stages for industry sectors. On the other hand, volumes are scaled down using the urbanisation rate (i.e.. urban population/total population).

The opportunity analysis is based on domestic use, meaning it includes imported volumes and excludes exports. This approach has been chosen as it allows a focus on urban waste levels and inefficiencies arising particularly at the consumption stage as well as new types of business models and services offered to Chinese urban dwellers. For nutrition, electronics, and textiles, this means that the calculated circular economy impacts are conservative – in addition to limiting our focus to opportunities affecting value chain steps relevant to the urban context, the (few) production levers considered are based on production volumes for local consumption only.

The interaction of opportunities for a given focus area has been taken into account, both to avoid double-counting in cases where the combined effect of opportunities is smaller than the sum of the individual opportunities, and to outline the amplified impact in cases where the reverse is true. Taking mobility as an example, the positive effect of remote and flexible working is comparatively lower when a multi-modal shared mobility system has been implemented as the mobility demand can be satisfied by fewer car kilometres. By contrast, the positive effects of designing vehicles to fit a circular mobility system are amplified when combined with a multi-modal shared mobility system

The circular opportunities were quantified for two scenarios – the current development path and the circular economy scenario, both for 2030 and 2040. While the former takes into account the key policies/targets devised by the government, as well as technological development and ongoing optimisation trends (such as implementation of emission standards in vehicles), the latter presents the additional impact of circular economy opportunities. The assumptions underlying each scenario build on leading expert opinions.

For each scenario, the potential impact on a unit basis as well as the penetration rate for each opportunity were estimated. For example, for the mobility opportunity 'Scale up remanufacturing and use more recycled materials', it was estimated as a first step how much of a vehicle could be made from remanufactured parts and recycled materials respectively. In a second step, this impact on a unit base was applied to the scope of the focus area – the remanufacturing of parts applied to selected categories of vehicles. Finally, the penetration rate was determined – the share of new vehicles that will come with such parts/materials in the current development path and in the circular economy scenario. The penetration rate was higher in the circular economy scenario than in the current development path in 2040 than 2030 in the circular economy scenario. However, due to a lack of long-ranging policy targets, the rate in the current development path was kept on the same level for 2030 and 2040. The impact per unit was assumed to improve especially for immature technologies. The detailed assumptions for the scenarios are presented in the sectoral tables that follow.

As with most sectors of consumption, when the costs fall, demand will rise. We have not quantified this in this report. However, previous research has shown that such a rebound effect can be lowered through a circular economy systems approach. Please refer to the *Growth Within* report for more details.[525] Taking the example of mobility, with a lower price for electricity than liquid fuel (and assuming the capital expenditure for electric vehicles (EV) infrastructure will decrease further), a shift to electric mobility can result in increased demand for private vehicles. But if such a shift is combined with the development of a shared and multi-modal mobility system, occupancy rates, as well as vehicle kilometres, can be increased to compensate.

TABLE 4: KEY ASSUMPTIONS THAT HAVE BEEN APPLIED ACROSS SECTORS

	Unit	2015	2030	2040
Population	Million ppl	1,376	1,416	1,428
Urbanisation rate	%	54%	67%	67%
Real GDP	Billion CNY	78,324	221,286	430,750
Urban GDP%	%	81.5%	94.6%	94.6%
Electricity production mix				
% by natural gas	%	3%	8%	8%
% by coal	%	69%	57%	57%
% by hydro	%	3%	8%	8%
% by nuclear	%	20%	15%	15%
% by renewables	%	5%	12%	12%
Currency	USD/CNY	6.23	6.23	6.23

TABLE 5: BUILT ENVIRONMENT

LEVERS	BASELINE 2015	CDP 2030
Relevant for all levers	• 90% of urban residential housing is commodity houses with the average size of 60m² • 10% of urban residential housing is affordable houses with the average size of 50m²	• 93% of urban residential housing is commodity houses with the average size of 90m² • 7% of urban residential housing is affordable houses with the average size of 75m² (financial support is expected to be invested in low-income housing in cities to offer a decent living space even for low-income family and immigrants, according to the 13th Five Year Plan) • • Government would put more emphasis on improving energy efficiency and combating environment pollutions (from 13th Five Year Plan)
Design for longevity Modular, flexible, and durable design	• All the new build from 2015 will stand during the modelling period (from 2015 to 2040)	• 20% maintenance cost saving
Industrialised construction processes Standardised, modularised components are prefabricated off-site and then can easily be assembled on-site	• 1% of new building adopting advanced technologies in construction	• 10% of buildings in cities would be built by new construction technology • 20% waste reduction during construction
Share space to increase asset utilisation Underutilised assets could generate value by improving space utilisation	• 4.8% of urban population share residential space	• 10% urban residential houses are shared
Improve energy efficiency through 'green buildings' Green buildings seek to minimise negative, and create positive, impacts on the environment through energy and resource efficient designs	• 15% urban new build is green buildings	• 50% urban new built would be green buildings • water consumption is excluded in our model • green buildings reduce energy consumption up to 50%
Enhance productivity with 'smart buildings' A wide adoption of smart building equipment, such as sensors, data storage, and computing service	• The penetration rate of smart building is 5%	• The penetration rate of smart building is 20% • reduce energy consumption 20% • 4.8% commodity houses and 6.3% affordable houses would be both green & smart buildings (see green & smart stock simulation in the model)
Scale up reuse and recycling of construction and demolition waste Recycling and reuse of building components and materials. This can be enabled through material banks, modularity, better design for disassembly etc.	• 5% of construction and demolition waste is recycled • (no data about how much recycled materials are reused in new construction, so assume 5% mentioned above is reused)	• 30% construction and demolition waste in cities would be recycled • 14% CDW is reused in new build • 16% reduction of landfill

KEY ASSUMPTIONS		TOPICS COVERED
CE 2030	CE 2040	Modelled and/or Narrative
• Levers only focus on urban residential houses which is 31.56% of urban construction land in 2015	• 90% of urban residential housing is commodity houses with the average size of 90m^2 • 10% of urban residential housing is affordable houses with the average size of 75m^2	
• 40% maintenance cost saving	• 60% maintenance cost saving	**Modelled and included in narrative:** • commercial and public buildings
• 25% of buildings in cities would be built by new construction technology • 25% waste reduction during construction	• 55% of buildings in cities would be built by new construction technology • 55% waste reduction during construction	**Modelled and included in narrative:** • commercial and public buildings • existing buildings
• 15% urban residential houses are shared	• 40% urban residential houses are shared	**Modelled and included in narrative:** • commercial and public buildings • space sharing is just one of the solutions to optimise the utilisation of space • digitalisation (virtual working, digital platform) and integrated with mobility together
• Green buildings reduce energy consumption up to 50%	• green buildings reduce energy consumption up to 70%	**Modelled and included in narrative:** • commercial and public buildings
• smart buildings reduce energy consumption 20% • 10% commodity houses and 14% affordable houses would be both green & smart buildings (see green & smart stock simulation in the model)	• Smart buildings reduce energy consumption 40% • 21% commodity houses and 33% affordable houses would be both green & smart buildings (see green & smart stock simulation in the model)	**Modelled and included in narrative:** • commercial and public buildings
• 60% construction and demolition waste in cities would be recycled • 20% CDW is reused in new built • 40% reduction of landfill	• 90% construction and demolition waste in cities would be recycled • 45% CDW is reused in new built • 45% reduction of landfill	**Modelled and included in narrative:** • modelling construction and demolition waste, apply for new built and demolished buildings

TABLE 5, CONTINUED: MOBILITY		
LEVERS	KEY ASSUMPTIONS	
	BASELINE 2015	CDP 2030
Relevant for all levers Only passenger mobility within the city is included in model, not cargo	• Between 2015 and 2030, the demand for mobility is assumed to increase by 400%, driven by population growth, urbanisation, and rising incomes • 13th Five Year Plan: Development of urban mobility across Chinese cities from 2016–20. It aims to realise a smart urban mobility infrastructure by 2020, with projected annual ridership of 120 billion • China's Ministry of Industry and Information Technology (MIIT) and China Society of Automotive Engineers announced a detailed roadmap aiming to ensure that highly or fully autonomous vehicles would be on sale in the country by 2025. By 2030, 10% of vehicles on the market could be autonomous • In 2016, China's National Development and Reform Commission eased legislation to allow foreign investments in electric vehicles (EVs), so facilitating the government target of rolling out 5 million EVs on China's roads by 2020	
Facilitate multi-modal shared mobility Mobility as a service: public transport, leasing, car-sharing; multi-modal integration through common platforms	• Share of passenger-kilometres by cars 57% • Share of car-kilometres by shared cars 15%	• Share of passenger-kilometres by cars 52% • Share of car-kilometres by shared cars 17%
Scale up remanufacturing and use more recycled materials Remanufacturing of gearbox and steering column for example, design for disassembly, use of recycled/ recyclable materials	• 7% of total materials used is remanufactured • 19% of total materials used is recycled	• 9% of total materials used is remanufactured • 55% of total materials used is recycled
Design vehicles to fit a circular mobility system Improvement of engine performance, use of light-weighting, design for purpose		• 11% of reduction of car weight
Scale up zero-emission forms of propulsion	• 0.5% of car-kilometres is electric • 95.5% of car-kilometres is gasoline • 0% of car-kilometres is hydrogen • 4% of car-kilometres is CNG	• 14% of car-kilometres will electric • 80% of car-kilometres will be gasoline • 1% of car-kilometres will be hydrogen • 5% of car-kilometres will be CNG
Encourage remote and flexible working		• Demand for mobility can be decreased due to virtual work by 5%

		TOPICS COVERED
CE 2030	CE 2040	Modelled and/or Narrative
• The share of passenger-kilometres by cars will further drop to 47% • Share of car-kilometres by shared cars 30%	• The share of passenger-kilometres by cars will further drop to 43% • Share of car-kilometres by shared cars 49%	Included in the model: various modes of transportation: innercity bus, urban rail, cars, two-wheelers, bicycles – all included in the model **Additionally in narrative:** City design – overlap between built environment and mobility system – only in narrative
• Assumed that government will change the policy which currently hinders remanufacturing. Currently by law, end-of-life automotive components such as engines, steering parts, gearboxes, and front and rear axles must be treated as waste and sent for recycling rather than being remanufactured • 15% of total materials used is remanufactured • 60% of total materials used is recycled	• 23% of total materials used is remanufactured • 65% of total materials used is recycled	Remanufacturing and recycling included in the model
• The latest fuel-efficient standards could be further improved and design for purpose and light-weighting could play important roles • 18% of reduction of car weight	• 21% of reduction of car weight	Lightweight design and design for remanufacturability, and design for purpose included in model Additionally covered in narrative design modular design
• 34% of car-kilometres will electric • 57% of car-kilometres will be gasoline • 3% of car-kilometres will be hydrogen • 6% of car-kilometres will be CNG	• 60% of car-kilometres will be electric • 25% of car-kilometres will be gasoline • 9% of car-kilometres will be hydrogen • 6% of car-kilometres will be CNG	Included in the model: Electric, battery/fuel/cell, hybrid, CNG
• Demand for mobility can be decreased due to virtual work by 7%	• Demand for mobility can be decreased due to virtual work by 15%	

TABLE 5, CONTINUED: NUTRITION		
LEVERS	BASELINE 2015	CDP 2030
Relevant for all levers		`
Regenerate soil with urban food waste and wastewater Implement source-separated collection of urban waste and waste sorting Deploy compostable plastics to improve food waste recovery Recover nutrients and other building blocks from sewage sludge		Source-separated collection target of 90% is achieved by 2030; The treatment mix follows the Municipal Solid Waste non-hazardous treatment policy; and food treatment pilot capacity is available.
Expand business models that promote effective agricultural supply chains (outside of urban scope)		*(For modelled lever only – New Business & Operational Models)* It is assumed that penetration of new business models in general will **at least contribute half of the supply by 2030 in CDP and reach best-in-class level by 2040** **Slow development of rural cooperatives:** hindered by lack of incentives from farmer side and high entrance barriers of private capital due to strict land transfer system **Weak enforcement of contract law** **Lack of financing tools and insurance** **Low feasibility of peri-urban and urban farming due to excessively high cost:** vertical farming products cost ~10x of non-vertical farming products]

KEY ASSUMPTIONS		TOPICS COVERED
CE 2030	CE 2040	Modelled and/or Narrative
Materiality in each value chain step, by food category. Based on food loss and waste as a percentage of total food available at the beginning of this stage: all food loss and waste over 6.8% (based on median food loss % across value chain, food categories and 153 countries) is considered material and justifies a bottom-up effort; for all food loss and waste less than 6.8% a top-down method was applied. **Urban context.** Total food loss and waste volume were scaled down along urbanisation rate (i.e.. urban population/total population), in effect assuming the diet structure is the same for rural and urban population – this is a simplification. **Key drivers.** Identify drivers of areas with significant food loss and waste share. Identify key and quantifiable drivers for material assumptions. If key drivers too difficult to quantify bottom-up, use top-down method (e.g. education campaigns)		
Source-separated collection target of 90% is achieved by 2030; oil and fat from retail and household wastage is converted to biodiesel; remainder looped for Anaerobic Digestion (AD) and converted to energy and soil improver by 2040; OPEX for non-traditional treatment methods reduced to 80% due to technology improvement.		Both modelled and covered in the narrative
(For modelled lever only – New Business & Operational Models) Assuming faster development than CDP (i.e. in year 2030 reach the level of 2040 in CDP). In addition**, urban farming** would take off for **fresh fruit and vegetable,** (assuming that through subsidies, production cost of vertical farming could be reduced to at-par level of field produce.) Penetration of new models would reach 85% for grain & oilseed (G&O) and protein, and 90% for fruits & vegetables **Key drivers include:** • Land transfer system allowing private sector involvement • Better enforcement of contract law and more sophisticated agriculture financing and insurance tool • Technology breakthrough to reduce **vertical farming cost by at least 50% by 2030 and 90% by 2040**	Penetration of new models would reach 90% for G&O and protein, and 100% for fruits & vegetables	'New models': Modelled and covered in the narrative **Covered in the narrative:** • Reduce losses of agricultural output • Adopt resource-efficient farming practices • Adopt regenerative agricultural practices • Apply sharing economy concepts

Optimise food storage, transport and processing Build grain storage capacity Develop cold chain capacity for fruit & vegetables in post-harvest and downstream distribution by aggregating demand and improving utilisation via sharing concept Invest in processing & packaging technology and equipment to process volume that cannot be sold to fresh market and to reduce losses due to poor operational handling		**Baseline:** • Current cold chain penetration rate is 22% for fruit & vegetables, 34% for meat and 41% for aquatic product in China, compared to over 95% penetration rate and a mere 2% food loss in North America, Western Europe, and Japan • In general, upstream cold chain infrastructure is poorer than downstream in-city delivery and last-mile delivery • Cold chain market is fragmented, with top 15 refrigerate warehouse operators only occupying 12% of total market • Due to huge upfront investment, most cold chain market players have single-digit or even negative net profit margin **CDP:** Penetration of cold chain storage and transportation would reach average developed country level in 2030 in CDP. As a consequence, food loss in storage, transportation, and processing would be reduced to level of 2% and will further drop to best-in-class level of 0.5% by 2040 (from 15% in fruit & vegetable and 9% in protein) **Key drivers:** **Growth trend:** In China refrigerated warehouse capacity grew at 35% year-on-year from 2008–2014; refrigerated vehicle capacity grew 10% in 2015; overall market size is projected to grow at 15% year-on-year to 2020 **Favourable policy:** NDRC issued Agricultural Products Cold Chain Logistics Development Plan in 2010 and specifically stated cold chain penetration target; cold chain development is again mentioned in 13th Five Year Plan **Rising demand:** Rising awareness of food security and freshness among consumers drives new business models such as farm-to-consumer direct sourcing, which drives investment in cold chain transportation; fresh food as share of total food online retail market has grown from 3% to 18% from 2010 to 2013
Design out loss and waste of food in the retail system Improve operations and aesthetic demands to reduce food loss in retail marketplaces Maximise the use of currently unmarketed products		In-store loss remains the same as in the baseline
Reinforce food consumption patterns beneficial to health and the environment Change consumption behaviours in urban households Address high wastage of food consumed away from home (FAFH) Slow down dietary change towards over-consumption and increased beef consumption and promote sustainable food concepts		Impact from pure consumer awareness campaign will reach average UK (pilot) level (on average the whole country reduced 2% yearly)

Assume faster development than CDP (i.e. in year 2030 reach the level of 2040 in CDP) **Key drivers include:** • **Stricter regulation and enforcement:** e.g. maintain stricter control on food security beyond consumption stage towards more upstream value chain stages; establish standards based on scientific measurement • **Higher consumer willingness to pay premium for safer and fresher food:** to make high-quality cold chain transportation profitable • **Improvement in operational capability:** more specialised cold chain operators participate in the market instead of downstream user companies such as Yurun and Bright	Losses remain at 2030 CE levels since those are best-in-class levels	**Modelled:** • Cold chain • Processing & packaging investments **In addition covered in the narrative:** • Grain storage (this was not modelled because it falls largely outside of the urban scope)
In-store loss 20% lower than in the baseline (and hence than in CDP case)	In-store loss 30% lower than in the baseline (and hence than in the CDP case)	Both modelled and covered in the narrative
12% less loss	20% less loss	Both modelled and covered in the narrative

TABLE 5, CONTINUED: TEXTILES

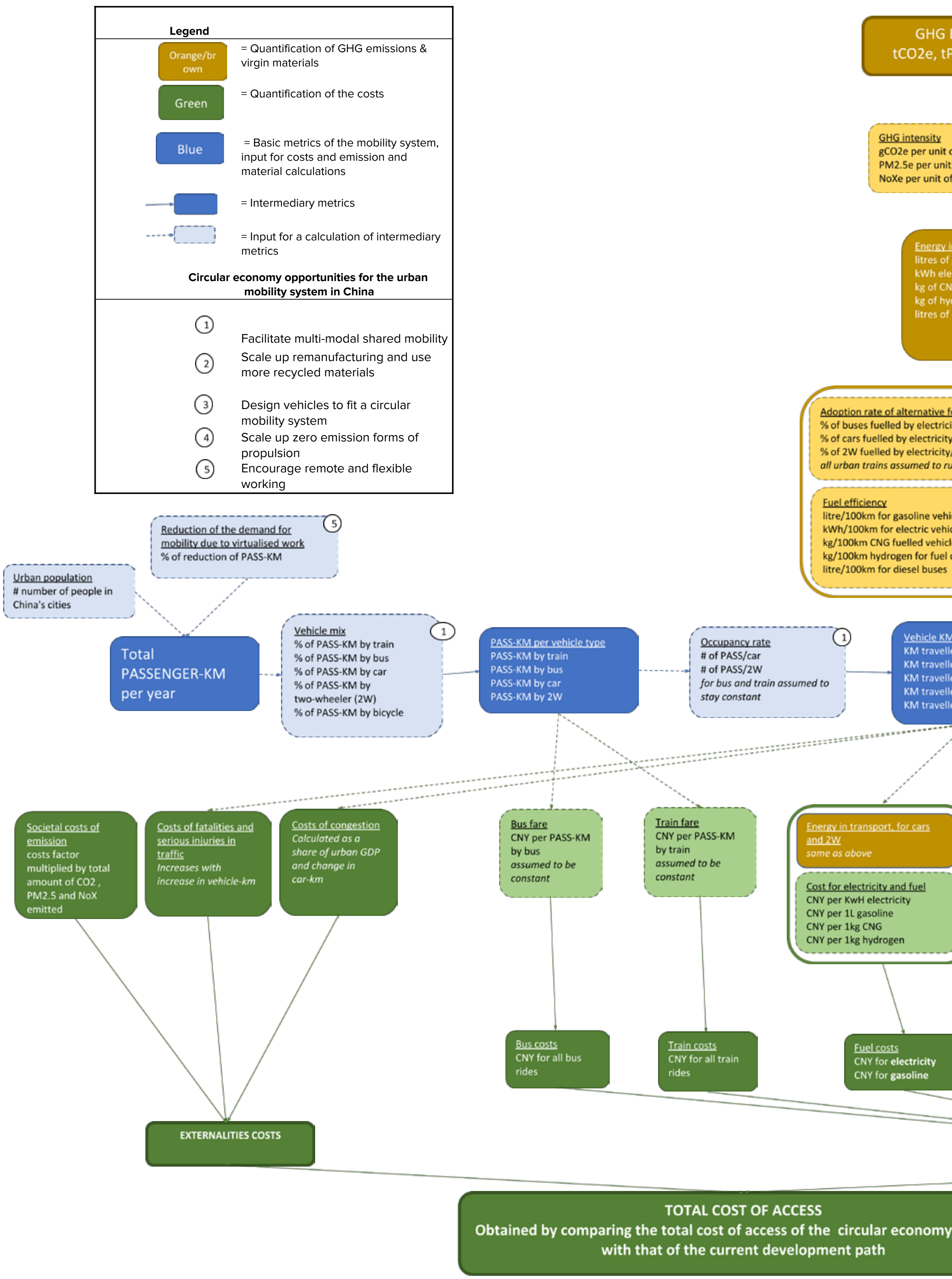
LEVERS	BASELINE 2015	CDP 2030
Pursue business models that increase utilisation of textiles **Increased utilisation of durable garments** Renting, leasing, and remarketing of durable garments	• In 2015, it is assumed that the increased utilisation of garments through new business models is less than 1% (1% of the population reusing 15% of its garments)	• By 2030, increased utilisation of garments is assumed to remain at less than 1%
Increased utilisation of durable textiles Renting, leasing, and remarketing of durable home and technical textiles	• In 2015, it is assumed that the increased utilisation of home and technical textiles through new business models is less than 1%	• By 2030, increased utilisation of home and technical textiles is assumed to remain less than 1%
Scale up recycling **Mechanical recycling** The disassembling, cutting and shredding of post-consumer discarded textiles. Shorter textile fibres are produced with lower quality than virgin fibres	• Total textile and garment collection rates are around 10%; in city pilot projects or as part of charity organisations • Low mechanical recycling rates (calculated in model)	• Total textile and garment collection rates are around 10%; in city pilot projects or as part of charity organisations • Low mechanical recycling rates (calculated in model)
Chemical recycling A depolymerisation and repolymerisation process breaking down pre- or post-consumer fibres back to monomers. Fibres of equal quality to virgin ones are produced that can be recycled infinitely	• Total textile and garment collection rates are around 10%; in city pilot projects or as part of charity organisations • Chemical recycling rates less than 1% • Lack of alignment between stakeholders, and market demand is limited	• Total textile and garment collection rates are around 10%; in city pilot projects or as part of charity organisations • Chemical recycling rates less than 1% • Lack of alignment between stakeholders, and market demand is limited
Introduce resource efficient measures Represented by: automation and 3D printing, efficient water and energy practices, water recycling and treatment, efficient wash care practices	• Production yield of 65% • 30% water efficiency improvement (12th Five Year Plan) • 20% energy efficiency improvement (12th Five Year Plan) • Industry recycling rate of 15% (assuming 50% of the industry is recycling 30% of its water) • Full compliance to water quality standards (for wastewater discharge) • High wash frequency. Assumption: 61% washing machine ownership (machine wash 2x a week); 78% handwash (handwash 2x day)	• Production yield of 65% • Implementation of, and compliance to, policies and targets within 13th Five Year Plan i.e. 20% water efficiency improvement, 18% energy efficiency improvement • Industry water recycling rate of 15%, same as 2015 • Full compliance to water quality standards (for wastewater discharge) • Greater household water consumption due to the high frequencies of machine and hand wash

KEY ASSUMPTIONS		TOPICS COVERED
CE 2030	CE 2040	Modelled and/or Narrative
• Trend towards more value added products and services • By 2030, increased utilisation of durable garments will have increased to 2.3% (15% of the population reusing 15% of its garments)	• Greater social acceptance regarding renting/ leasing of clothes • By 2030, increased utilisation of durable garments will have increased to 9% (30% of the population reusing 30% of its garments)	• Design for durability • Maintenance services • Customisation and personalisation of garments
• Increased market demand, development of new business cases • By 2030, increased utilisation of home and technical textiles will have increased to 1% (5% of businesses reusing 15% of their home and technical textiles through their business)	• Greater social acceptance regarding sharing/ renting/ leasing of clothes • By 2030, increased utilisation of home and technical textiles will have increased to 7% (23% of businesses reusing 30% of their home and technical textiles through their business)	• Design for durability • Maintenance services
• Assumed to be in development: infrastructure, supporting policies and incentives, technological innovation, market demand • Total textile and garment collection rates could be increased to 41%	• Assumed to be in development: infrastructure, supporting policies and incentives, technological innovation, market demand • Total textile and garment collection rates could be increased to 56% (derived from Germany's current recycling rate of 75%)	
• Assumed to be in development: infrastructure, supporting policies and incentives, technological innovation, market demand • Design for recycling taking place in alignment with present recycling technologies • Chemical recycling rates increased to 6%	• Technological innovation and breakthroughs, and increased market demand • Design for recycling taking place in alignment with present recycling technologies • Chemical recycling rates increased to 16%	• Design for recycling • Aligning material design with recycling technologies • Advanced sorting
• • Greater implementation of technologies and practices that enable lower consumption of energy and water across the supply chain • Higher yields from the increased use of automation • Average industry water recycling rate, 37% • Full compliance to water quality standards (for wastewater discharge) • Greater awareness and better wash care of textiles and garments by households, decreasing water consumption of washing	• Greater implementation of technologies and practices that enable lower consumption of water and energy across the supply chain • Higher yields from the increased use of automation, and 3D printing • Average industry water recycling rate, 40% • Full compliance to water quality standards (for wastewater discharge • Increased ownership of washing machines, greater awareness and better wash care of textiles and garments by households	• Designing-out hazardous substances • Microfibres

TABLE 5, CONTINUED: ELECTRONICS		
LEVERS	KEY ASSUM	
	BASELINE 2015	CDP 2030
Relevant for all levers	**Consumption**: Baseline rates based on retail sales projections; urban-to-total rate assumed same across all products **Cost**: Cost composition of one electronics device considered same as cost composition of each of its parts **Granularity:** Full range of scoped product types aggregated into 11 product categories with similar analysis-relevant characteristics	2015 market data is taken as the proxy for All levers' penetration/consolidated effect **Improvements**: Improved rates (see below) are based on the explicit targets included in the 13th Five Year Plan
Capture the value of e-waste through recycling	**Collection rate (vs EoL volumes):** 15% **Recycling rate (vs collected):** 100%	**Collection rate (vs EoL volumes):** 40% **Recycling rate (vs collected):** 88%
Reuse and refurbish products, and remanufacture parts	**Refurbish and remanufacture**: Assumed non-existent in the baseline because of negligible level of activity (in this sector) in 2015	Refurbished products are created in the ye are included in put-on-market volumes wh **Refurbish:** 8% **Remanufacture:** 4%
Encourage product-as-a-service models	**PAAS models**: Assumed non-existent in the baseline because of their negligible market share in 2015	**Penetration rate** **Sharing:** • 5% for heating/cooling machines, home laundry appliances, vacuum cleaners • 0% for all other categories **PPU:** • 21% for kitchen appliances and personal care appliances • 5% for home laundry appliances and vacuum cleaners • 0% for all other categories

IPTIONS		TOPICS COVERED
CE 2030	CE 2040	Modelled and/ or Narrative
product price, commodity price, and energy cost across the board grow linearly after the effect first comes into play		
Collection rate (vs EoL volumes): 45% **Recycling rate (vs collected):** 76% – this is lower than in the CDP scenario because a growing share of collected volumes shifts towards refurbishing and remanufacturing	**Collection rate (vs EoL volumes):** 65% (fast 2030–40 growth due to stagnant collection rate 2015–30 for subsidised products and ramp-up in smaller loops **Recycling rate (vs collected):** 51%	**Modelled:** collection and recycling
ar after they become end-of-life and are sold in that same year. Refurbished products ile remanufactured products are not (since only parts are harvested)		**Modelled:** • Remanufacturing • Refurbishing
Refurbish: 16% **Remanufacture:** 8%	**Refurbish:** 50% **Remanufacture:** 25%	
Sharing / People sharing per device: 50 for home laundry appliances and vacuum cleaners; 3 for all other categories – this rate is kept constant over time because number is assumed to be driven by practicality rather than by uptake **PPU / Effect on product life span:** Based on replacement cycles in Germany vs China. It ranges from no effect for product categories with high technical obsolescence (e.g. mobile phones, personal computers) to doubling in case of very mature products (e.g. irons, vacuum cleaners) **Penetration rate**: The penetration rate for each model – product category combination (see below) is based on a score that is derived from the following factors: intimacy to owner, utilisation rate, ability to delineate a single 'use', technical obsolescence, and capex requirement. The conventional business model has its own penetration rate, set at 100% initially; the penetration rate for new models was subtracted from that 100% to obtain the new rate. It is expected that in certain instances there will be an overlap between the two models – this is approximated by multiplying the penetration rate of each model.		**Modelled:** • Sharing models • Pay-per-use (PPU)
Penetration rate **Sharing:** • 9% for heating/cooling machines, home laundry sppliances, vacuum cleaners • 0% for all other categories **PPU:** • 35% for kitchen sppliances and personal care appliances • 9% for home laundry appliances and vacuum cleaners • 0% for all other categories		

FIGURE A1: THE COSTS OF THE MOBILITY SECTOR IN CHINA



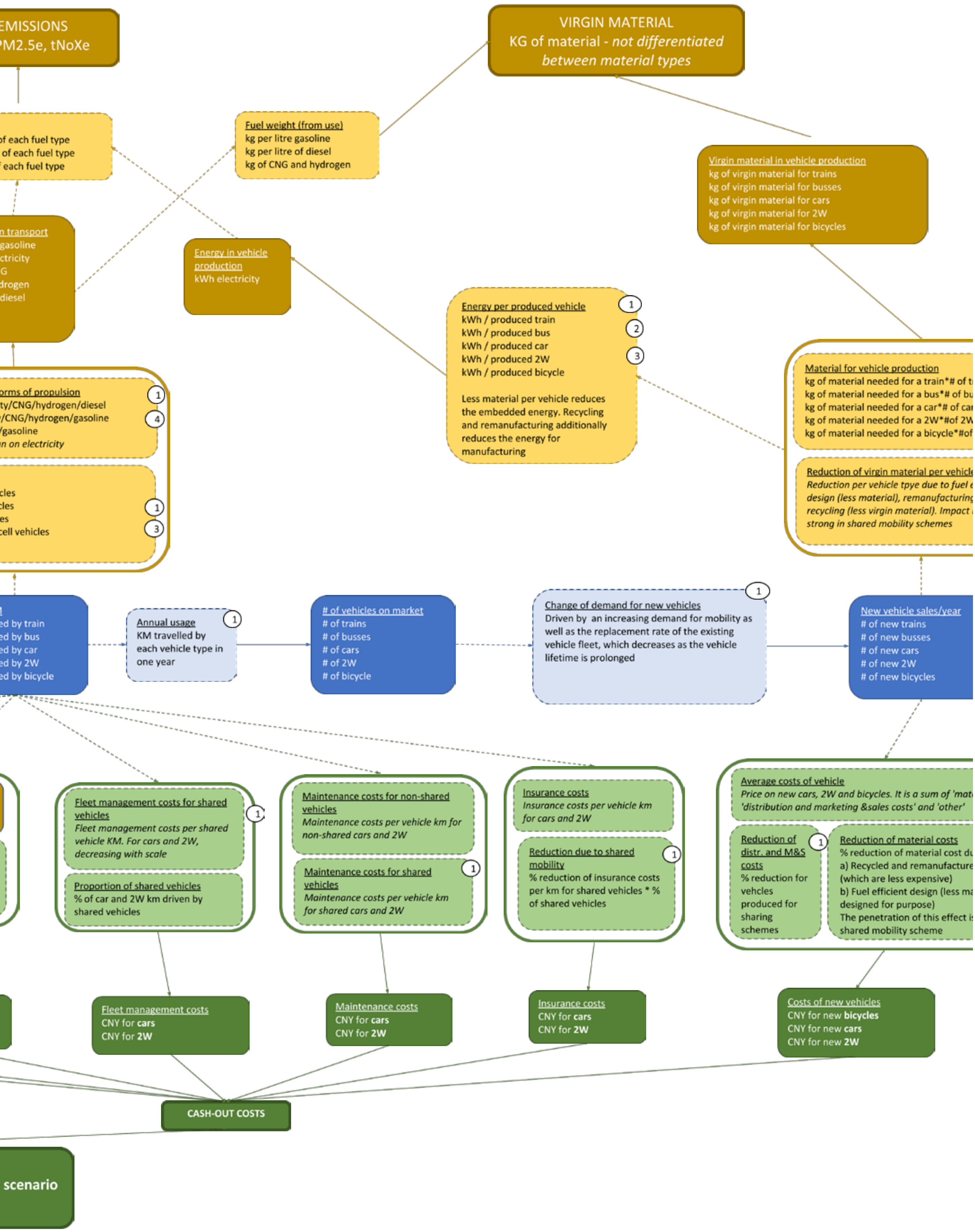
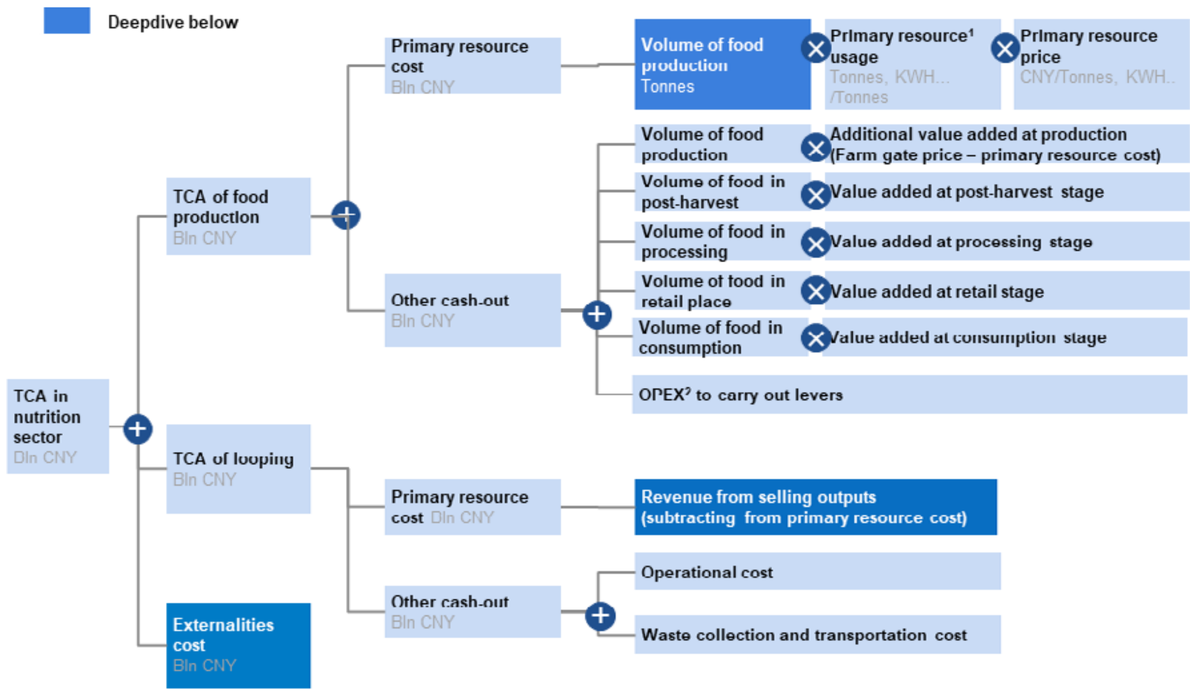
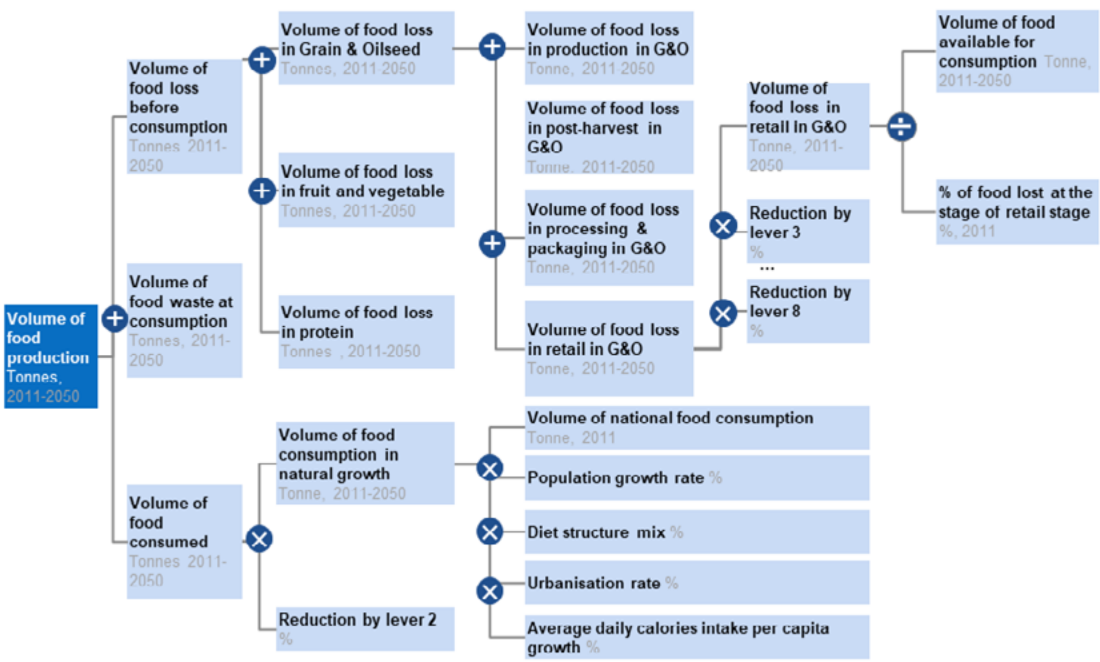

EMISSIONS
PM2.5e, tNoXe
VIRGIN MATERIAL
KG of material - not differentiated between material types
Fuel weight (from use)
kg per litre gasoline
kg per litre of diesel
kg of CNG and hydrogen
Virgin material in vehicle production
kg of virgin material for trains
kg of virgin material for busses
kg of virgin material for cars
kg of virgin material for 2W
kg of virgin material for bicycles
Energy in vehicle production
kWh electricity
Energy per produced vehicle
kWh / produced train
kWh / produced bus
kWh / produced car
kWh / produced 2W
kWh / produced bicycle
Less material per vehicle reduces the embedded energy. Recycling and remanufacturing additionally reduces the energy for manufacturing
Material for vehicle production
Reduction of virgin material per vehicle
Reduction per vehicle tpye due to fuel
Annual usage
KM travelled by each vehicle type in one year
# of vehicles on market
# of trains
# of busses
# of cars
# of 2W
# of bicycle
Change of demand for new vehicles
Driven by an increasing demand for mobility as well as the replacement rate of the existing vehicle fleet, which decreases as the vehicle lifetime is prolonged
New vehicle sales/year
# of new trains
# of new busses
# of new cars
# of new 2W
# of new bicycles
Fleet management costs for shared vehicles
Fleet management costs per shared vehicle KM. For cars and 2W, decreasing with scale
Proportion of shared vehicles
% of car and 2W km driven by shared vehicles
Maintenance costs for non-shared vehicles
Maintenance costs per vehicle km for non-shared cars and 2W
Maintenance costs for shared vehicles
Maintenance costs per vehicle km for shared cars and 2W
Insurance costs
Insurance costs per vehicle km for cars and 2W
Reduction due to shared mobility
% reduction of insurance costs per km for shared vehicles * % of shared vehicles
Average costs of vehicle
Reduction of distr. and M&S costs
% reduction for vehcles produced for sharing schemes
Reduction of material costs
Fleet management costs
CNY for cars
CNY for 2W
Maintenance costs
CNY for cars
CNY for 2W
Insurance costs
CNY for cars
CNY for 2W
Costs of new vehicles
CNY for new bicycles
CNY for new cars
CNY for new 2W
CASH-OUT COSTS
scenario

FIGURE A2: NUTRITION DRIVER TREE, TCA



1 Include water, fertiliser, pesticide, land and energy 2 Only include energy related OPEX

FIGURE A3: NUTRITION DRIVER TREE, FOOD PRODUCTION



ABOUT THE ELLEN MACARTHUR FOUNDATION

The Ellen MacArthur Foundation was launched in 2010 to accelerate the transition to a circular economy. Since its creation the charity has emerged as a global thought leader, establishing circular economy on the agenda of decision-makers across business, government and academia. With the support of its Core Philanthropic Partners SUN, MAVA and People's Postcode Lottery and Knowledge Partners Arup, IDEO, McKinsey & Company and SYSTEMIQ, the Foundation's work focuses on five interlinking areas:

Learning

Developing the vision, skills and mindsets needed to transition to a circular economy

The Foundation emphasises interdisciplinary, project-based and participatory approaches, encompassing both formal education and informal learning. With a focus on online platforms, the Foundation provides insights and resources to support circular economy learning, and the systems thinking required to accelerate a transition.

The Foundation's formal education work includes Higher Education programmes with partners in Europe, North and South America and Asia, international curriculum development with schools and colleges, and corporate capacity building. Informal learning work includes the global online Disruptive Innovation Festival, and development of the Circular Design Guide in collaboration with IDEO.

Business and Government

Catalysing circular innovation and creating the conditions for it to reach scale

Since its launch, the Foundation has emphasised the real-world relevance of the circular economy framework, recognising that business innovation sits at the heart of economic transitions. The Foundation works with its Global Partners (Danone, Google, H&M, Intesa Sanpaolo, NIKE Inc., Philips, Renault, Solvay and Unilever) to develop scalable circular business initiatives and to address challenges to implementing them.

The Circular Economy 100 programme brings together industry leading corporations, emerging innovators, affiliate networks, government authorities, regions and cities, to build circular capacity, address common barriers to progress, understand the necessary enabling conditions, and pilot circular practices, in a collaborative, pre-competitive environment.

Insight and Analysis

Providing robust evidence about the benefits and implications of the transition

The Foundation works to quantify the economic potential of the circular model and develop approaches for capturing this value. Its insight and analysis feeds into a growing body of economic reports highlighting the rationale for an accelerated transition towards the circular economy, and exploring the potential benefits across stakeholders and sectors.

The circular economy is an evolving framework, and the Foundation continues to widen its understanding by working with international experts, key thinkers and leading academics.

Communications

Engaging a global audience around the circular economy

The Foundation communicates circular economy ideas and insight through its circular economy research reports, case studies and books. Through digital media it aims to reach audiences who can accelerate the transition, globally. The Foundation aggregates, curates, and makes knowledge accessible through Circulate, an online information source providing unique insight on the circular economy and related subjects.

Systemic Initiatives

Transforming key material flows to scale the circular economy globally

Taking a global, cross-sectoral approach to material flows, the Foundation is bringing together organisations from across value chains to tackle systemic stalemates that organisations cannot overcome in isolation.

Plastics was identified through initial work by the Foundation with the World Economic Forum and McKinsey & Company as one of the value chains most representative of the current linear model, and is the focus of the Foundation's first Systemic Initiative. Applying the principles of the circular economy, the New Plastics Economy initiative, launched in May 2016, brings together key stakeholders to re-think and re-design the future of plastics, starting with packaging. Building on the success of this first Systemic Initiative, textile fibres became the Foundation's second material stream focus, with the launch in May 2017 of Make Fashion Circular.

More information:
ellenmacarthurfoundation.org
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LEGAL NOTICE

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