China Council for International Cooperation on Environment and Development

Circular Economy (CE) in China

Scoping Study 2024

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Executive Summary

According to UNEP (2024), the annual global extraction of materials has grown from 30.9 billion tons in 1970 to 95.1 billion tons in 2020, and is expected to reach 106.6 billion tons in 2024. Thus, the prolonged growth of the global demand for materials is associated with major environmental concerns. In addition, high raw material consumption is a risk factor with regard to energy and raw material supply. The principles of a Circular Economy provide a clear pathway to address high raw material consumption and the inherent environmen¬tal problems. By closing material cycles, CE can also help to overcome resource scarcities and supply risks.

When it comes to CE and respective policies, China has a long tradition. In general, there is a broad agreement on the relevance of the circular economy in China as well as on the successes and challenges related to its implementation. With the aim of addressing these and narrowing down possible further work in a broad field of CE, proposals for focus sectors and potential Special Policy Studies (SPS) were identified using desk research, expert interviews, field visit in Beijing and digital consultation of experts. The identified sectors are plastics (incl. packaging), batteries, renewable energy technologies, textiles and construction.

Several SPS are possible in each of these sectors. However, the following are recommended based on experts' feedback:

(1)Analyze the contribution of the plastic industry (incl. packaging) to GHG emissions in China and assess the potentials for reductions,

(2)Map the value chain of EV-battery recycling in China and analyze the material and economic flows as well as costs and benefits of EV battery recycling,

(3)Identify policy instruments for improved collection and recycling of raw materials from the renewable energy technologies,

(4)Analyze the market and material flows of waste textiles, economic operators, and the envi-ronmental and economic potential of implementation of fiber-to-fiber recycling in China,

(5)Prepare a feasibility study on implementing Extended Producer Responsibility (EPR) in Waste Electrical and Electronic Equipment (WEEE), packaging waste and End-of-Life-Vehicles (ELV) in China,

(6)Assess the feasibility of circular public procurement in the building and construction sector in China and draw conclusions for circular public procurement in general.

The current global and national debate in China also suggests studying the impact and potential of CE for achieving industry decarbonization and climate neutrality. This question can be investigated with a comprehensive CE modeling and has been recommended in this study as a potential cross-sectoral SPS.

In relation to policies with high relevance and impact, this scoping study derived three recom-mendations for consideration in the development of the 15th Five Year Development Plan and for the outstanding reform of the Circular Economy Promotion Law:

**The co-leaders and members of this study serve in their personal capacities. The views and opinions expressed in this study report are those of the individual ex-perts participating in the study team and do not represent those of their organiza-tions and CCICED.*

(1)Continue setting numerical targets and indicators including a resource productivity target to enable responsible consumption of raw materials in China, adding waste reduction targets in relevant sectors, mainstreaming the implementation of waste hierarchy principles (R-Strategies), defining a clear hierarchy of different recycling options based on their envi-ronmental impact and recycling, and setting targets for recycled content at sectoral and ma-terial-level

(2)Implement ambitious framework-setting instruments, such as minimum ecodesign standards, circular public procurement, extended producer responsibility in relevant sectors and fi-nancial mechanisms, for creating a level-playing field for circular business models, and

(3)Link circular economy to the industry decarbonization and climate neutrality targets of China and explicitly integrate CE measures into China's Nationally Determined Contributions (NDCs).

This study provides a good basis for further bilateral cooperation between China and Germany in the field of circular economy within the framework of the Sino-German Environment Partnership.

Key words：Circular Economy, Textiles, Renewable Energy Technologies, Plastics, Batteries, Construction, Macroeconomic Modelling, Industry Decarbonization, Climate Neutrality

contents

1 Objectives and approach

The high demand for raw materials in a largely linear economy is one of the main causes for the climate crisis, pollution, and biodiversity loss. According to UNEP (2024), over 55 per cent of greenhouse gas emissions (GHG) and 40 per cent of the health effects of particulate matter are caused by the extraction and processing of material resources. The transition to a circular economy is crucial for the achievement of global and national climate and environmental goals, as it reduces the use of primary resources and the associated emissions as well as the pressure on ecosystems and biodi-versity.

The concept of circular economy has been at the center of attention in China for several years, which is also reflected in the work of the China Council for International Cooperation on Environment and Development (CCICED) to date[1]. Furthermore, China's 14th Five-Year Development Plan sets out key tasks and indicators to measure progress in the implementation of the circular economy in China.

The goal of this study is to support CCICED in the identification of relevant areas for further research and policy implementation in the field of circular economy in China. The study has the following specific objectives:

1.Identify and prioritize environmentally relevant sectors for a circular economy in China,

2.Define effective and appropriate circular economy measures in the identified sectors,

3.Analyze the feasibility of modelling the ecological and socio-economic potentials of im-plementing a comprehensive circular economy in China (building on the experiences of the study "Modell Germany Circular Economy")

4.Define research areas for potential Special Policy Studies (SPS) on circular economy, and

5.Derive recommendations for the implementation of a comprehensive circular economy in China.

The study is based on a comprehensive literature review on the current status of circular economy implementation in China as well as interaction with and continuous feedback from international and Chinese circular economy experts (selected by CCICED), e.g., through regular meetings and an online consultation. Furthermore, interviews with circular economy experts in government, the private sector, academic institutions, and civil society in China, as well as a one-week field visit to Beijing from 13 May 2024 to 17 May 2024, also contributed substantially to the study.

The overarching goal of the study is to contribute to the development of policy recommendations to be considered in the 15th Five Year Development Plan and in the reform of the Circular Economy Promotion Law in China. The study also seeks to strengthen the bilateral cooperation between China and Germany in the field of circular economy as part of the Sino-German Environment Partnership (BMUV; NDRC 2024).

[1]In this regard, the CCICED discussion paper The New Era of Green Development – China's Green Transition to 2050 (2017), the Special Policy Study (SPS) Sustainable Consumption and Green Development (2013) and the SPS Major Green Technology Innovation and Implementation Mechanisms (2020) are few examples that emphasise the importance of a circular economy for reducing the environmental impact of production and consumption in China.

2 Current state of circular economy implementation in China

China has been the first country to introduce Circular Economy (CE) as a basic principle of its policy (OECD; EC 2019). In 2005, a policy framework including principles, goals and key tasks was proposed ("Opinions on accelerating the development of circular economy"), followed by the 11th Five-Year Develop¬ment Plan (FYDP), which mainly focused on resource productivity (especially energy). The Circular Economy Promotion Law (CEPL) was subsequently published in 2008, fo-cusing on 3R strategies (Reduce, Reuse, Recycle), and later revised (2017) to place a greater emphasis on the circularity of industrial systems. Originally, the focus of CE in China was primarily on resource efficiency and end-of-life waste management. With regard to circular economy, the 14th Five-Year Development Plan (FYDP) (2021-2025) prioritizes resource productivity, recycling and waste uti-lization by setting national targets and clearly highlighting the importance of CE as an approach to tackling climate change and achieving carbon neutrality by 2060.

The interplay between resources and carbon neutrality has played an increasingly important role in the design of circular economy policies (Wang et al. 2021b): The key targets of China's green low-carbon transition – known as the 'dual carbon goals' and as also issued in the two key documents: "*Opinions of the Central Committee of the Communist Party of China and the State Council on Completely, Accurately, and Comprehensively Implementing the New Development Concept to Well Implement the Work of Carbon Peaking and Carbon Neutrality* (the Opinion) and Action Plan for Peaking Carbon Emissions before 2030 – are to peak CO_2 emissions before 2030 and achieve carbon neutrality before 2060 (UNCTAD 2023). Furthermore, the NDRC published the '*Guiding Opinions on Coordinating Energy Conservation, Carbon Reduction, and Recycling to Accelerate the Updating and Renovation of Product Equipment in Key Fields'* in 2023 (Chinese version cited in UNCTAD 2023). Therein, NDRC emphasizes the importance of 'large sorting, processing, and trading centers of wastes' including incentives for consumers such as trade-in and cash pledge, as well as green procurement and green labeling. Wind turbines, photovoltaic solar panels, and power batteries are mentioned, the recycling and reuse of which will be further standardized' (UNCTAD 2023). Furthermore, CE in China includes a range of environmental indicators (e.g. energy and water consumption and pollutant emissions) and addresses key issues of growth and development (OECD; EC 2019; Fan und Fang 2020). A recent study shows the major contribution that a CE can give to carbon reduction in China (CACE 2023b).

The National Development and Reform Commission (NDRC) is the leading authority in the development of CE regulations, other ministries are in charge of their respective programs (Ble-ischwitz et al. 2022). CE projects are implemented at micro (enterprise/product), meso (industrial symbiosis, mainly through eco-industrial parks) and macro (provinces/country as a whole) levels (OECD; EC 2019; Vlieger de Oliveira; Mahut 2023a).

Another important driver is commodity security (Bleischwitz et al. 2022): Due to its enormous growth since 1990 and its increasing global relevance in the production of goods, China has a high demand for commodity imports, which leads to a strong dependence on commodity prices and supply chains disruptions. This shows that a future CE development pathway could significantly reduce China's dependence on imports in addition to the ecological effects.

Achievements

China's resource productivity (i.e., the ratio of gross domestic product (GDP) to resource consumption) doubled between 1990 and 2015. According to Vlieger de Oliveira; Mahut (2023a), resource productivity increased by 26% between 2015 to 2020. Although this indicator is used by many countries, it is unsuitable for demonstrating actual success in environmental and resource protection: the increase in resource productivity is mainly due to economic growth, as absolute resource consumption, including the environmental impacts thereof, increased over the same period (Bleischwitz et al. 2022).

In China, the circularity rate for non-metallic minerals increased from 2.7% to 5.8% between 1995 and 2015 from an input socioeconomic cycling rate perspective, reflecting the increasing share of secondary materials. Furthermore, circularity of non-metallic minerals in terms of 'output so-cio-economic cycling rate' (OSCr) rose from 7.2% to 17%, reflecting progress in industrial solid waste management. (Bleischwitz et al. 2022; Wang et al. 2020).[2] In comparison, 11.5% of the material resources used in the EU in 2022 came from recycled waste materials: Between 2010 and 2022, the rate increased from 10.7% to 11.5%. (Eurostat 2023)

A report by EMF (2018) estimates that a CE development pathway could reduce China's greenhouse gas emissions by 23% by 2040 and reduce the consumption of non-renewable resources by between 8% and 71% by 2040, depending on the focus area. For Germany, a study by Oeko-Institut (2023) found that the measures in the ambitious scenario could reduce CO_2 emissions by 26 % and raw material consumption by 27 % compared to a business-as-usual in 2045.

Existing challenges for a CE in China

Besides achievements and a tradition in the field of CE policies, there are also challenges that hinder its implementation. First of all, as CE is a multi- and cross-sectoral topic, there are coordination challenges among various ministries and agencies. Further examples are challenges of implementing CE measures in resource-intensive industries that are fundamental to the economy, or arranging financial support when there is a high dependence on government funding in CE projects (Vlieger de Oliveira; Mahut 2023a). It is noteworthy mentioning that the stated challenges are inherent to a multi- and cross-sectoral topic of a CE, and not necessarily restricted to China. Similar challenges can be identified in many other countries, including EU.

Coordination difficulties occur also at company, sector, and regional levels (Bleischwitz et al. 2022). Uneven development is also an obstacle that relates to the asymmetry between sectors; while high-tech and export-oriented manufacturing sectors are more advanced in greening their operations, other sectors (e.g. agriculture, construction) are lagging behind (Vlieger de Oliveira; Mahut 2023a). There are also regional imbalances; for instance, the CE development level of 31 Chinese provinces was assessed by Fan und Fang (2020) in 2017. The authors found that there are still large differences between regions and only 23% of the provinces are relatively efficient. Such implementation gaps exist due to "economic imperatives at the provincial level, bonus systems for policymakers if they meet their respective planning goals, a tax system favoring growth and budget issues over environmental concerns, and prevalence of environmentally-intensive 'zombie industries' that are kept alive due to social concerns" (OECD; EC 2019).

[2] In 2020, a comprehensive utilization rate of 86%, 56% and 50% was achieved for crop straw, bulk solid and construction waste re-spectively, as well as the utilization of 54.9 million tons of wastepaper and 260 million tons of scrap steel (Vlieger de Oliveira; Mahut 2023a). In 2015, resource recycling saved nearly 200 million tons of standard coal and reduced emissions of 9 billion tons of wastewater and 1.15 billion tons of solid wastes (Fan und Fang 2020). It is worth mentioning that eco-innovation has been an essential aspect.

Another obstacle is the failure of CE projects after initial success for reasons such as govern-ment-driven approaches, implementation gaps and path dependencies (Bleischwitz et al. 2022). Due to limited research funds, comprehensive evaluations of CE in China are still rare, as is quantitative systemic research on CE performance, especially concerning the differing circumstances of Chinese provinces (Fan und Fang 2020). Further challenges include the high level of investment required in recycling facilities, and the lack of public awareness of CE (Vlieger de Oliveira; Mahut 2023b).

Bleischwitz et al. (2022) also highlight implementation gaps between pioneers and transforming majorities, emphasizing that SMEs are lagging behind the large companies in moving towards a CE, as well as difficulties in creating a boosting market for secondary materials.

Raw material supply for future technologies

By expanding waste collection and recycling infrastructures and increasing the use of secondary raw materials, a circular economy contributes significantly to the security of raw material supply, independence from raw material imports and the reduction of the environmental impact of primary raw material extraction and processing.

On the one hand, more than a third of all materials (around 31.3 billion tons) were extracted in China in 2020, on the other hand, the country was the largest net importer of materials (over 2,000 million tons) in the same year (UNEP 2024). Recycling can be a reliable and sustainable supply of secondary raw materials, and product design can consider the use of secondary raw material as well as design for recycling.

Due to its role in raw material extraction and processing, China is a hotspot country for green-house gas emissions, harmful particulate matter emissions from industrial sources and other impacts (UNEP 2024). The further development of critical technologies implies additional raw material de-mand and environmental impacts. For example, China's consumption of rare-earth minerals grew at an average annual rate of 7.5% between 2004 and 2014, increasing its share of global consumption from 43 to 70%; and the production of rare-earth end-use products grew by about 70% between 2005 and 2015 (CSIS 2021).

Gender aspects of a Circular Economy

Globally, women play a big role in the waste management sector and in circular economy (CE). With regards to gender aspects of CE, gender-specific behaviour in consumption, e.g., in terms of expanding products' lifespan through repair, and in waste segregation and disposal can be distin-guished from gender-specific jobs in production and manufacturing.

With regards to waste management, a global online survey (ISWA Women of Waste Task Force 2023) found that women reported "a sense of purpose working in the waste sector". However, women are predominantly represented in the low-value areas of waste treatment and are underrepresented in product design, management and the development of advanced technologies. In addition, female entrepreneurs in the waste sector reported difficulties in obtaining loans. In this study, interviewees reported that recycling and transport are dominated by male workers in China. However, since the aspect of waste segregation has become more prominent, female workers are also beginning to play a role: It has been reported that women are working in the position of teachers or multiplicators who provide training and raise public awareness about waste segregation. This observation is supported by UN Women (2019). An ongoing EU project could serve as best practice to accelerate this trend: 'Girls Go Circular' supports "schoolgirls, and more broadly, any student, to develop their digital and leadership skills while learning about the circular economy and finding solutions for a sustainable future."

In terms of gender-specific behaviour when buying and handling items, according to UN Women (2019) and others, women make more sustainable consumption decisions and are more sensitive to ecological, environmental and health issues than men. Research has shown that they are more likely to make environmentally friendly purchases, minimise waste and recycle.

From a broader point of view, gender aspects in CE could be considered together with other aspects such as the formalization of informal sectors under the umbrella of 'just transition'.

3 Sectoral perspectives

3.1 Selection of environmentally relevant sectors in China

A global, Multi-Regional Input-Output (MRIO) model was used for an initial screening of the relevant industrial sectors. For this study, sector-specific, consumption-based environmental impacts were estimated for three different impact categories: raw material consumption (RMC), global tem-perature potential (GTP) and land use (LU). This was done using EXIOBASE v3.8.1 (Stadler et al. 2018; Stadler et al. 2021) in conjunction with the python package 'pymrio' (Stadler 2024). Version 2022 of EXIOBASE was used for this study. The resulting uncertainties, which add to the inherent uncertainties of MRIO tables in general, were considered acceptable for an initial, economy-wide screening. However, the figures given in this section are not to be understood as precise calculations, but rather serve as rough estimates. The estimates for RMC, GTP and LU were validated against literature values and expert judgement. More details on the modelling approach, including a graphic layout of the results, as well as the interpretation of the results of the MRIO analysis can be found in Annex I.

The RMC in China for 2022 amounts to roughly 28.5 Gt, with 77 percent originating from abiotic resources such as minerals, metals and fossil fuels and 23 percent stemming from biotic resource extraction such as food and fodder crops or wood products. The most relevant individual sectors were the construction industry contributing with 36.7 percent, the health and social work sector (14.5 percent) and cattle farming (5.8 percent). Together, the 20 most important sectors account for around 89 percent of Chinese raw material consumption.

The GTP of Chinese consumption was estimated at 12.8 Gt CO_2-eq for 2022. The most relevant sectors were again construction, health and social services and cattle farming. The top 20 industries contribute to 88 percent of China's GHG emissions, with the construction sector alone accounting for around 43 percent of emissions.

Cattle farming accounts fort the largest share of the land use footprint at 18.7 percent, followed by the construction sector (13.3 percent) and health and social work (7.6 percent). Together, the top 20 sectors account for around 82 percent of Chinese land use.

A longlist of sectors was compiled taking into account the results of the MRIO analysis as well as the expected future technologies and material demands (see chapter "Raw material supply for future technologies"). It included: Construction, (Manufacture of) vehicles and batteries, (Manufacture of) wearing apparel/textiles, Plastics/packaging, Electric and electronic equipment and machinery, Health sector, Hotels and gastronomy, Metallurgy, Agriculture and farming, Renewable energy installations, Digitalization & Artificial Intelligence, Retail & trade, Robotics and Additive manufacturing & 3D-printing.

3.2 Proposed sectoral focus for Special Policy Studies (SPS)

Annex III describes trends, best practices and barriers to a circular economy for the environ-mentally relevant sectors in China. For the purpose of a more targeted approach to be pursued under the potential SPS on circular economy, the following criteria were applied for further sectoral prior-itization:

- Environmental relevance (based on the sector analysis in chapter 3.1),

- Policy relevance: Synergies with the development in the EU product policy (desk research),

- Technology relevance: Future trends and technology development (chapter 2),

- Feasibility of implementation (based on expert feedback in Annex V),

- Specific interest shown by the experts during the interviews (expert judgement),

- Complexity of the sector (expert judgement as well as expert feedback in Annex V).

Following the evaluation of the sectors based on the above-mentioned criteria, the following sectors were recommended to be focused on in a possible SPS: (1) Plastics (incl. packaging), (2) Batteries, (3) Renewable energy technologies, (4) Textiles and (5) Construction.

In addition, a cross-cutting topic was identified for modelling the impacts of a circular economy in the industry sectors to demonstrate the contribution of the circular economy to achieving the climate neutrality target of China. This topic is discussed further in chapter 4.2.

3.3. Specific development and challenges for selected sectors in China

This chapter provides a rationale for the prioritization of four sectors for a possible sectoral SPS. A description of all sector-specific developments and challenges analyzed (long list) can be found in Annex III.

Plastics / packaging

China is the largest manufacturer, user, and exporter of plastics in the world. The average annual growth rate of China's packaging production between 2018 and 2020 was 8.7%. Of the 60 million tons of plastic waste generated in 2020, approximately 35% were landfilled, 37% incinerated, and only 26.7% recycled (EMF 2022). Building a circular value chain for plastics is important for China's plastics objectives as well as for carbon emissions and broader environmental goals (EMF 2022). In the 14th Five-Year Plan, China has set the following targets for the plastics sector: (1) Reduce single-use plastic production and consumption at source, (2) Improve plastic waste collection and recycling, (3) Establish the whole chain management system of plastic pollution, (4) Reduce plastic waste leakage (EMF 2022). Since 2016 in particular, the attention paid to plastics has increased significantly, with a major focus on prohibitive bans and information campaigns. Policy instruments, especially economic incentives, have only recently become popular. In recent years, there has been a diversification in the policy instruments used, the types of plastics addressed and the aspects of the value chain considered, as well as a clear intention to build a circular plastics value chain (Fürst und Feng 2022). In the coming years, a stronger regulatory focus on initiatives to eliminate plastic pollution is expected (with the aim of reducing the plastic leakage into the environment, especially into the oceans) (Fürst und Feng 2022). There is also a trend towards the use of biodegradable plastics, which is not without problems (Greenpeace East Asia 2020). In addition, there is a strategy to promote bamboo as a substitute to plastic (The State Council of the People's Republic of China 2023b). The boom of e-commerce and increase of (food) deliveries has led to a significant increase in packaging waste. These sectors have therefore been the focus of several studies and political measures Other policy priorities were dealing with agricultural plastic film, marine litter and microplastics (Liu und Liu 2023).

Policies and standards for the packaging value chain are currently mostly voluntary, siloed or overlapping (EMF 2022). A circular concept for the plastic packaging industry is not fully integrated into current policy initiatives (e.g. initiatives for zero-waste cities or waste sorting schemes) (EMF 2022). So far, the focus has mostly been on downstream measures (such as recycling) and not on upstream measures (e.g. waste prevention solutions) (EMF 2022; Fürst und Feng 2022). Although regulations are in force in some regions, there is a lack of implementation and penalty (e.g. for SUPs used in food delivery; Lu 2024).

In addition to packaging, chemicals in plastic products also give rise to health concerns, e.g., due to plasticizers (phthalates, bisphenols, e.g. BPA, BPS, BPF), flame retardants, poly- and perfluorinated alkyl substances (PFAS), etc. In 2019, the European Environment Agency issued a warning about plastic children's toys imported from China that contained dangerous chemicals, for example.

Batteries

It is expected that the number of private vehicles in China will continue to increase (Gan et al. 2020). The stock of electric vehicles is also increasing significantly (Statista 2024). There may be restrictions on the sale of fuel cars, as some cities in China have already introduced (Gan et al. 2020; Liu et al. 2020a). Such restrictions could reduce the current growth of the car stock in China, but enhance the share of electric vehicles and thus batteries (Gan et al. 2020) (Wesselkämper et al. 2024). The risks of metal supply (apart from lithium) can be reduced by cobalt-free battery technology in combination with efficient recycling systems (Hu et al. 2024). The supplementary capacity of sec-ond-life EV batteries may be useful for China's prospective novel energy storage applications (Hu et al. 2024). However, Wesselkämper et al. (2024) argue that there is a conflict between circularity and a longer product life, so that the benefits of a second use (reuse) need to be evaluated depending on the prioritization of objectives.

The switch from combustion engines to battery-powered electric vehicles[3] poses new challenges for the treatment and recycling infrastructure and capacities. In macroeconomic terms, this transition will lead to a lower demand for primary raw materials, as less fossil fuels will be needed. In the vehicle/battery sector, however, critical and strategic metals in particular will initially be in high demand. Cars are getting bigger and heavier, both in terms of combustion engines and electric vehicles . Currently there is little incentive to take ecological assessments into account in the design of vehicles. The recycling rate of end-of-life vehicles is low. In 2018, the recovery rate for end-of-life passenger vehicles was less than 18% of the quantity scrapped (Liu et al. 2020c).

Renewable energy installations

China has set itself ambitious targets for the expansion of renewable energies, and capacity is expanding rapidly (Climate Cooperation China 2023). An increased volume of EOL wind turbines and photovoltaic modules are therefore expected in the coming years (Yang et al. 2023; Ali et al. 2023). The waste streams may be unevenly distributed across the country, e.g. for PV waste. Wang et al. (2022a) find that there will be a concentration in the northern or north-western

[3]The International Council on Clean Transportation (2023): Trends of New Passenger Cars in China: Air Pollutant and CO_2-Emissions and Technologies, 2012-2021, Yuntian Zhang, Hui He and Zhinan Chen, https://theicct.org/wp-content/uploads/2023/03/China-PV-trends_final-v2.pdf; accessed: 13.09.2024

regions. In terms of timing, it is found that over 80% of the total cumulative PV waste will be generated between 2040–2050. In 2023, the Chinese authorities published guidelines to promote the recycling of decommis-sioned wind power and photovoltaic equipment (The State Council of the People's Republic of China 2023a). The publication of standards for the recycling of wind turbines was announced for January 2024 (Ng 2024).

There are challenges for both PV and wind turbines. Currently, there is a lack of technologies and capacities for cost-competitive, high-quality recycling of wind turbine rotor blades (Yang et al. 2023). This also applies to large-scale infrastructures for the reuse and recycling of solar photovoltaic modules, which are hampered by high costs for the recycling of the modules and therefore low economic benefits (IEA 2022). Zhou et al. (2024) state that innovating, or improving the existing PV recycling process, and encouraging low-energy and low-emission technologies could help to reduce recovery costs and increase recovery income, thereby stimulating market interest. Furthermore, there are other bottlenecks in PV recycling: the current concentration of PV waste recycling in small en-terprises and self-employed people (without environmental protection measures and with corre-sponding environmental risks and material losses), the wide dispersion of PV modules in China, and the lack of clear policy guidance for PV panel decommissioning (which results in difficult access to recycling, complex cross-regional flows, inconsistent recycling technologies, unsmooth circulation routes and other problems) (Zhou et al. 2024).

Furthermore, heat pumps are considered an important technology for the decarbonization of heating in China (Su und Urban 2021; IEA 2024b; GIZ 2024). Circular design and circular business models are therefore necessary for this technology to help to reduce resource consumption.

Textiles

In 2014, China accounted for 55% of global textile production and generated 70% of the world's synthetic fibres. China is not only "the world's largest fibre producer, but it is also the world's largest textiles exporter, and the largest textiles machinery manufacturer" (EMF 2018). China's rapid eco-nomic growth and urbanisation coupled with a growing middle class, "tripled the domestic demand for textiles and will grow threefold yet again over the next decade" (EMF 2018). It is predicted that China's clothing sales (2016: 6.5 kg) may rise to 11-16 kg per person by 2030, which would put China on a par with North America (EMF 2018). Overall, the linear 'take-make-dispose' approach dominates the production and consumption of textiles. There is a trend towards the relocation of textiles manu-facturing plants from the east of the country to western and central regions to counteract rising wages and production costs (EMF 2018). Textiles are also an e-commerce trend, "with an online shopping adoption rate of almost 60%" (EMF 2018).

Of China's textile waste (20–26 million tons annually), only a small proportion is recycled (CACE 2023a). Government announced in 2022 that the recycling rate for used textiles should be 25 per cent by 2025. By 2030, a rate of 30 percent and 3 million tons of recycled fibres are to be achieved[4]. The Chinese state has promoted the recycling of used textiles in recent years, for example through tax concessions and financial support. However, there is still a lack of a comprehensive recycling system and efficient utilisation of textile waste (Fashion United 2022; Akter 2024).

In 2018, the textiles industry was the third largest water consumer in the country, consuming approximately three trillion litres each year (EMF 2018). In addition to water consumption, there is also the water pollution caused by the dyeing of textiles and other treatment processes. In the last decade, however, research has focussed intensively on the treatment of textile wastewater (Huang et al. 2021).

[4]State Council of the People's Republic of China (2022): China to up its textile recycling capability, https://english.www.gov.cn/statecouncil/ministries/202204/20/content_WS625f649fc6d02e5335329a8f.html; Accessed: 13.09.2024

The prevailing market conditions and the cost structure have resulted in short-life textile products being imported and offered at low prices mainly by bulk buyers from countries with lower labour costs and low labour and environmental standards (Dudin et al. 2015). There is an excessive focus on the export sector, and a lack of effective control over the import and export of textile raw materials and products (Dudin et al. 2015). In addition, enterprises lack own financial resources as well as access to bank loans, which are necessary to upgrade manufacturing (Dudin et al. 2015). As in other all other parts of the world, circular business models are largely unable to compete with this global supply market. There are low prices for new goods, short-lived designs and a limited willingness or ability to repair textiles and use second-hand goods (low societal appreciation of textiles). A lack of take-back systems and low economic efficiency in sorting hinder the optimization of the collection and recycling of used textiles. Thus, there is a lack of incentives for technical innovations and investments at the end of the life cycle of textiles and ultimately for a circular design.

Construction

The urbanization trend in China is at an unprecedented pace, resulting in substantial demand for new housing and infrastructure. In 2016, the built-up area under construction and completed built-up area accounted for half of the world's new construction; and by 2030, China's urban population will reach one billion people (EMF 2018). At the same time, the average lifespan of a building is only 25 – 30 years, which is due to the use of low-quality materials to reduce construction costs (EMF 2018). The building sector is characterized by a high consumption of primary materials (e.g., China produces and consumes around 55% of cement globally), resulting in significant greenhouse gas emissions. GHG emissions from concrete, steel, bricks and aluminium account for around 90% of the GHG emissions from buildings (UNEP 2023). China now accounts for more than 18% of total CO_2 emissions in the global building sector (having surpassed the EU in 2011) (EMF 2018).

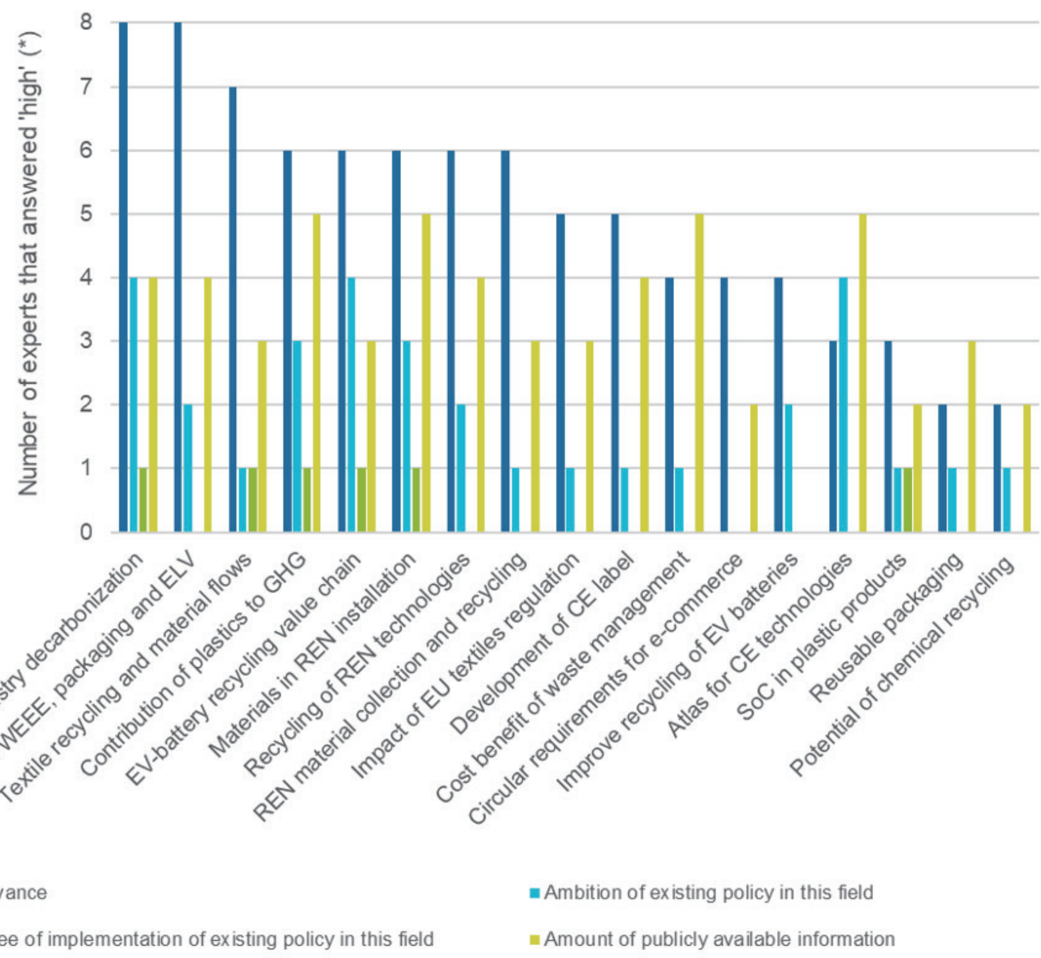
Due to the fast-advancing urbanization and short lifespans of buildings, about 2.36 billion tons of construction and demolition waste (CDW) were produced annually in the period 2003-2013 (Zheng et al. 2017). This corresponds to 30 to 40% of the total amount of waste generated in China (Huang et al. 2018). Only about 5% is recycled or reused (Huang et al. 2018). Furthermore, most of this share is reused for road gravel instead of being utilized in the construction industry. Therefore, the con-struction sector faces multiple challenges, in particular the fact that the preservation and continued use of existing buildings and infrastructure is not prioritized over resource- and space-intensive new construction. Most existing regulations target treatment rather than the reduction of CDW, and few regulations require CDW reduction during the architectural design stage (Huang et al. 2018). Fur-thermore, there is an under-developed market for reused or recycled CDW products (Huang et al. 2018). As there is little awareness of reuse, deconstructability and recycling during the construction of buildings, it is often not possible to provide unmixed material streams from the secondary raw ma-terial store.

4 Recommendations for potential Special Policy Studies (SPS)

A comprehensive long-list (Annex VI) of potential topics for SPS had been developed based on desk research, exchange with the international and Chinese experts in the CE Scoping Study working group and direct interviews with several stakeholders before and during the field visit of Oeko-Institute's experts in Beijing. Applying the criteria mentioned in '3.2 Proposed sectoral focus for Special Policy Studies (SPS)', a short-list (Annex IV) had been selected and was submitted to the experts for their assessment (see the full results in Annex V).

Figure 1 shows experts' ranking of the short-list of potential topics for SPS (also in Annex IV). The two topics with the highest ranking are "CE in industry decarbonization" and "Extended Producer Responsibility (EPR)" in terms of its relevance followed by one or more topics per selected sector.

Figure 1: Expert ranking of possible SPS topics.



Note: (*) Experts had four options to answer ('high', 'medium', 'low', 'I don't know')
Source: Expert consultation in the course of this study (see Annex V).

4.1 Sectoral SPS

Based on the experts' estimation of relevance (see Figure 1) and the selection of environmentally relevant sectors (see chapter 3), the six most important sectoral SPS topics were proposed:

Table 1: Five most relevant sectoral research questions for SPS on CE

Research Question	Considerations based on experts' feedback
Analyze the contribution of the plastic industry (incl. packaging) to GHG emissions/ carbon budget in China and assess the potential for reductions	● Urgent need to decarbonize the plastic industry as well, move away from fossil-based feedstocks and replace them with bio-based and especially secondary resources. ● Plastic packaging and packaging in online deliveries should be included. ● The macro data on plastic consumption in China is available, obtaining this data will be difficult for the SPS itself. ● Beyond the contribution to GHG emissions, efforts should be made to analyze in detail the impact of the plastics industry on other types of pollution (e.g. particulate matter or chemical pollution) and the impact on biodiversity, e.g. through modelling studies such as The PEW Charitable Trusts; Systemiq (2020) that could be built upon and applied specifically to China.
Map the value chain of EV-battery recycling in China and analyze the material and economic flows as well as costs and benefits of EV battery recycling in the value chain.	● The EV-battery recycling sector in China is developing rapidly (Wes-selkämper et al. 2024). The current battery recycling capacity amounts to more than 500,000 metric tons. The 14th FYDP sets the goal of establishing a complete battery recycling system by 2025. ● China is improving its regulatory framework to better trace and manage the battery value chain. The Ministry of Industry and Information Technology (MIIT) has introduced guidelines to improve traceability and transparency in the production and recycling of batteries (Zhao et al. 2021b, Yang and Fujikawa 2023). ● Such a study could focus on a better understanding and identification of optimization potential, sustainable technology adoption, standardisation, environmental management and system integration (reuse in the energy transition).
Policy instruments to improve the collection and recycling of raw materials from renewable energy technologies (REN)	● This is a topic where decarbonisation and CE go hand in hand. Experts say that policy should focus on CE in manufacturing in general rather than in the manufacturing of REN, and that measures that contribute to decarbonising REN production could be identified and their potential explored. ● The focus of such a study should be determined based on literature review and existing studies focussing on China (Shao et al. 2023; Li et al. 2023; Sanchez Molina 2023). There is also increasing publicly available information on material demand (IEA 2024a). The choice of topic should take into account that strategies that minimize the need for future energy infrastructure and thus improve strategic autonomy and reduce pressure on critical mineral supplies should be prioritized. , UNEP (2024), for example, shows that with smart city design, and optimized access to service it would be possible to reduce global energy demand by 27% by 2060. This study could also include the collection and recycling of raw material from renewable energy installations. ● China requires all renewable energy projects, including wind, solar, and hydro installations, to undergo rigorous Environmental Impact Assessments (EIA) before approval. ● Out of the three different suggestions for potential SPS related to REN, exploring policy instruments such as design-for-recycling, take back obligations, deposit return schemes etc. seems to be of highest importance, aspects such as, reuse, repurposing and remanufacturing should also be analyzed closely. ● Potential to look on reuse (e.g. rare earth elements) or carbon fiber remanufacturing / reuse ● Experience from Germany shows that typical instruments (deposit returns, technical restrictions) don't work due to dynamic technology development. Hence, requirements for future contracts and management shall be developed considering the dynamic market structure of REN
Map the technologies for textile recycling and analyze the market and material flows of waste textiles, economic operators, environmental and economic potential of introducing fi-bre-to-fibre recycling in China.	● Given the large textile production capacities in China, it would be worthwhile to increase the output quantities and qualities of textile recycling as there is a huge market for the uptake of secondary fibre-to-fibre recyclate. ● In order to not only look at end-of-pipe solutions such as recycling. the topic could be explored in combination with a focus on ecodesign, in particular, the impact of the EU textiles regulation on the fashion and textile industry in CN, and provide a knowledge transfer on the EU Ecodesign for Sustainable Products Regulation.

Research Question	Considerations based on experts' feedback
Feasibility study on implementing Extended Producer Responsibility (EPR) in Waste Electrical and Electronic Equipment (WEEE), packaging waste and End-of-Life-Vehicles (ELV) in China.	● There have been studies for EPR in China in general (Yang and Fujikawa 2023; Zhao et al. 2021b) and in some sectors (e.g., batteries, Jiang und Zhang 2023). ● Future EPR research for China should focus on overcoming barriers such as standardizing recycling systems, and upscaling access to recycling infrastructure. ● Understanding the Chinese-specific context will be critical in designing implementable and effective EPRs.
Assess the feasibility of circular public procurement in the building and construction sector in China and draw conclusions for circular public procurement in general[5]	● It is generally acknowledged that public procurement has great market power, which can be used to reduce environmental impact and test new approaches. However, there are still challenges to making procurement not only sustainable but also circular, which can be studied in the building sector. ● The environmental impact of the building sector provides a solid rationale for the selection of potential SPS, e.g., chapter 3.1, e.g., construction and demolition waste (CDW) accounts for 30% to 40% of the total amount of waste in China (Huang et al. 2018). Furthermore, it is selected due to its large relevance for the public procurement. ● As potential SPS should build on existing studies, e.g., Huang et al. (2020), and select the scope based on the existing, relevant waste categories. One of the potential study's objectives could be the identification of measures to reduce CDW of relevant waste categories from public real estate to provide best practices. ● The aim is to learn from these best practices examples which standard procedures and monitoring framework could be derived for circular public procurement.

4.2 Cross-sectoral SPS

Given China's ambitious policy goal of achieving carbon neutrality by 2060 and the high level of interest shown by the experts, it is recommended to model the impact of the circular economy to achieve industry decarbonization and climate neutrality in China. All experts consulted believe that such a study would be highly relevant (Figure 1). According to the experts, a comprehensive and professional study on this topic does not yet exist in China. They are of the view that CE is an es-tablished policy area in China, whereas the link to decarbonization and climate neutrality has only recently emerged. Hence, policy implementation has so far focused on a few topics such as industrial energy efficiency. Examining both topics together in a quantitative analysis, showing the full range of circular economy measures and the impact of their implementation, could provide a 'boost' that seems to be significant.

To assess the feasibility of a comprehensive CE modelling, several macroeconomic modelling studies and their respective data basis for China were analyzed (see Annex II for detailed approach). In general, computable Global Equilibrium Models (CGE), Integrated Assessment Models (IAM), Environmentally-Extended, Multi-Regional Input-Output models (EE-MRIO) and Dynamic Material Flow Analysis (MFA) are all suitable model classes to evaluate circular economy measures on a national scale. A universal bottleneck for all model classes remains the availability of data, which is a particular challenge for an economy as diverse and rapidly changing as the Chinese economy. Experts point out that publicly available information in English is poor, while the availability of information in Chinese is somewhat better. For bottom-up modelling, process-based LCA is a theoretical option. It is well suited for the assessment of individual products or materials, provided the data is available, but does not translate well to systems as

[5]This sectoral research question for a potential SPS was developed at the end of the study based on the feedback from the final expert workshop. Therefore, it is not explicitly included in the long and short lists of potential SPS topics in the appendix

large as the Chinese economy. This is due to the fact that the system boundary is inevitably cut off, which means that a significant part of the economy is not covered. However, sub-sectors and key processes that influence environmental impacts, such as cement or steel production, can be quantified with a process-based LCA. The LCA results could be used for comparison with the macro-scale modelling results. All methods have their individual drawbacks and benefits (see Annex II for a detailed argumentation), therefore a hybrid approach of several model classes should be used to analyse systems as complex as the Chinese economy, as it was done, for example in work done by Circle Economy (2023) and UNEP (2024).

The feasibility analysis of the CE modelling reveals that comprehensive macroeconomic mod-elling for China is theoretically possible. However, quantitative models can only complement qual-itative research if data is available. A coarse-grained analysis of individual simplified scenarios can be carried out using macroeconomic Input-Output models, but stand-alone results have limited ex-planatory power and may therefore require complementary modelling approaches. A simple approach to estimating circularity potential is stock modelling, as this only requires time series data on sales, waste streams and average lifespans.

Given the availability of resources and data, it is recommended to focus on the most relevant sectors for a targeted CE modelling in the context of China (see chapters 3.1 Selection of environ-mentally relevant sectors and 3.2 Proposed sectoral focus for SPS).

5 Policy recommendations

Based on desk research, the exchange with international and Chinese experts in the CE Scoping Study working group and direct interviews with various stakeholders before and during the field visit of Oeko-Institut experts in Beijing, eleven overarching policy recommendations were identified for consideration in the 15th Five Year Development Plan and the reform Circular Economy Promotion Law in China. Based on feedback from Chinese and international experts (online consultation), the following three main policy recommendations are presented (for all recommendations see Annex IV List of potential topics for SPS and list of policy recommendations

Recommendation 1 – Continue setting numerical targets and indicators including a resource productivity target to enable responsible consumption of raw materials in Chi-na

China's increase in resource productivity (see 2 Current state of circular economy implementa-tion in China) shows its considerable progress in relatively decoupling the resource consumption from economic growth[6]. For the 15. FYDP, it is recommended to continue setting numerical targets for resource productivity, adding waste reduction targets in relevant sectors, mainstreaming the imple-mentation of waste hierarchy principles (R-Strategies), defining a clear hierarchy of different recycling options based on their environmental impact and recycling, and targets for recycled content at sectoral and material-level. As resources and their consumption patterns are so diverse, progress in resource policy cannot be monitored using a single indicator.

[7]Relative decoupling: "In relative decoupling the growth rate of the environmentally relevant parameter (such as resources used or environmental impact) is lower than the growth rate of the relevant economic indicator (for example GDP)", UNEP (2024).

Generally, targets can contribute to actively transparently communicating the necessary, struc-tural social change and setting a clear direction. Of course, social needs must not be forgotten in the process. Similar to the discussion on compensating for the social consequences of climate protection measures, resource policy should also be accompanied by social measures.

Recommendation 2 – Implement ambitious framework-setting instruments for cre-ating a level-playing field for Circular Business Models

In view of China´s increasingly important role as manufacturer of final products, more and more strategic decisions are being made in China on the circularity of global material flows. The mix of instruments to enforce circular products and technologies in the mass market should include the following:

(a) Minimum ecodesign product standards (using the example of the EU Ecodesign for Sus-tainable Products Regulation). As the design of a product has major influence of the later impact of that very product onto the environment, eco-design is a crucial prerequisite for more circular value chains.

(b) Ensure that all legal requirements at all levels of government are consistently and effectively geared towards circular public procurement. Experts estimate that due to the sheer volume of public projects in China, mandatory circularity standards would have a major impact.

(c) Mandatory Extended Producer Responsibility (EPR) schemes for selected sectors, such as batteries, textiles and electronics. Extended producer responsibility is key to the transformation towards a circular economy – not only because it generates funding for waste management infra-structure, but also because it leads to economic incentives for companies to improve the circularity of their systems. In 2016, China introduced its EPR system, which obliges producers to assume re-sponsibility for waste. It covers a wide range of products, including electronics, batteries, vehicles, and packaging materials. Implementation is progressing, but there are still other challenges, such as the complex institutional design, the introduction of EPR, as recycling technology and public awareness are not the same as in other parts of the world. It is understandable that in a large country with regional differences and increasing consumption, the set-up is complex. However, building upon existing ambitious policies, best practice in other countries, scientific studies (see potential topics for SPS), and in combination with awareness trainings and incentives, EPR will greatly promote circularity in China.

(d) Financing mechanisms to mobilize private capital for circular investments (e.g., loans, transformation bonds, public-private partnerships, start-up financing, etc.). Experts say that currently, the diffusion of CE strategies and technologies to SMEs is seen as a weak point in the overall im-plementation of CE in China. So fiscal instruments would likely have a great impact, but it might prove difficult to implement them and ensure that they reach the SMEs that need them most. There also seems to be great potential for policy measures for SMEs.

For some of these instruments, there are already policies or pilot projects in China, for others not. They need to be (further) developed and will ultimately require consistent implementation.

Recommendation 3 - Link Circular Economy to China's industrial decarbonization and climate neutrality targets

Experts agree that linking CE to climate targets and implementation strategies would be very effective to combat climate change. Tools such as the UNDP/UNEP/UNFCCC's toolbox for integrating CE into NDCs could be used. The link between CE and the goal of climate neutrality has been rec-ognized in several high-level policy documents in China. However, according to experts, there is a gap in how CE is translated into targets for specific sectors to guide implementation, and a roadmap for a future development of CE in China is lacking.

6 Conclusion

There is a broad agreement on the relevance of the circular economy in China as well as on the successes and challenges related to its implementation. Political recognition of circular economy in terms of its contribution towards high-level policy goals, such as carbon neutrality, has already been explicitly stated in the important government opinions and action plans. Against this background, this study has built upon the existing knowledge on circular economy in China and has highlighted several areas of interventions and research, keeping in mind the environmental relevance of the proposals as well as future technology development and interests of a wide range of actors. Thus, all recom-mendations for potential Special Policy Studies (SPS) are justified from one angle or another. From the meta perspective, the link between CE and the dual goal of carbon neutrality in China by 2060 was supported by the majority of interviewees and consulted experts to be a positive one. Consequently, this is reflected in the cross-sectoral SPS recommendation on a study on modelling CE's contribution towards decarbonization and carbon neutrality in China. However, depending on the budget and time schedule for the SPS, a CE modelling for selected relevant sectors can also be considered, as it is recommended in the sectoral SPS on plastics.

Modelling CE at the economy or sectoral level is just one of many other identified topics in this study. Improving the information, knowledge and policy instruments for environmentally relevant sectors, such as textiles, EV-batteries and renewable energy installations, offer substantial research opportunities and thus have been recommended at the level of sectoral SPS. This also applies to the construction sector and enormous potentials of improvement that can be channelled in this sector using the instrument of (circular) public procurement, which is already well established in China.

In general, the range of topics identified in this study can be combined in different levels of detail to advance the discourse of CE in China. For instance, the instrument of (circular) public procurement can also be further developed for other sectors, such as textiles and plastics/ packaging. The selection of potential SPS topics can also be guided by the availability of data. This may apply to the recom-mendations on plastics or textiles.

In addition, the study makes three high-level policy recommendations for consideration in the 15th Five Year Development Plan and the reform of China's Circular Economy Promotion Law. Based on the experiences of the authors, experts and interviewees as well as scientific studies, the combi-nation of proposed targets and instruments represents a promising policy mix for mainstreaming CE in China.

It is important to emphasize that all sectoral and policy recommendations made in this study support the focus of bilateral cooperation agreed upon between China and Germany in the field of circular economy (BMUV; NDRC 2024). The framework of the Sino-German Environment Part-nership provides a solid basis for the follow-up of the identified set of potential research questions and topics of collaboration. The collaboration can benefit from the mutual exchange on success and challenges in implementing CE in both the countries.

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Annex to the Scoping Study

Annex I EXIOBASE Multi Regional Input-Output (MRIO) analysis

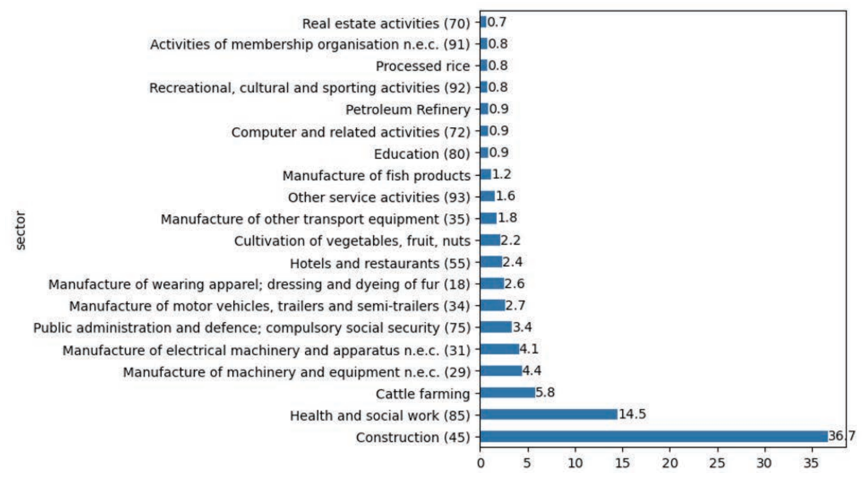
Input-Output tables are compiled from national inventories and trade statistics. They link final demand and industrial output of individual countries, regions and sectors to each other and thus allow analysis of international supply chains of bulk materials on a coarse-grained spatial and temporal resolution. Environmental extension tables relate these economic activities to specific environmental impacts and emissions.

EXIOBASE is a Multi-Regional Input-Output table (EE-MRIO) including 163 industries for 44 countries and five ‘rest of the world regions’. It was developed by harmonizing and detailing sup-ply-use tables for a large number of countries, estimating emissions and resource extractions by industry. The industry-by-industry format, as opposed to the product by product version follows the assumption of “fixed product sales structures”. This means that during the transformation from supply-use tables, primary and secondary outputs are mixed inside their respective industries, thus maintaining the integrity of the industry itself. On the other hand, product by product tables redefine industries by moving secondary production to those industries where they are characteristic outputs (Larsen 2018). As of version 3.8.1 of the EXIOBASE, the end years of real data points used are: 2015 energy, 2019 all GHG (non-fuel, non-CO2 are nowcasted from 2018), 2013 for material, 2011 for most others, land and water (Stadler et al. 2021). The authors of EXIOBASE estimated data points until 2022 based on a range of mainly trade and macro-economic data, while issuing a strong reminder that these estimates must be treated with care.

Six out of seven final demand categories, including final consumption of households, govern-ment and NGO’s as well as capital formation, inventory changes and changes in valuables but ex-cluding exports were considered for the consumption-based footprints of China according to the European Commission’s definition of consumption-based footprints, here using the example of RMC:

‘RMC captures the amount of domestic and foreign extraction of materials needed to produce the final products used by households, governments or non-profit institutions serving households, or used for gross capital formation. The indicator RMC, also known as 'material footprint', takes a domestic consumption perspective by excluding exports […]’ (European Commission 2018).

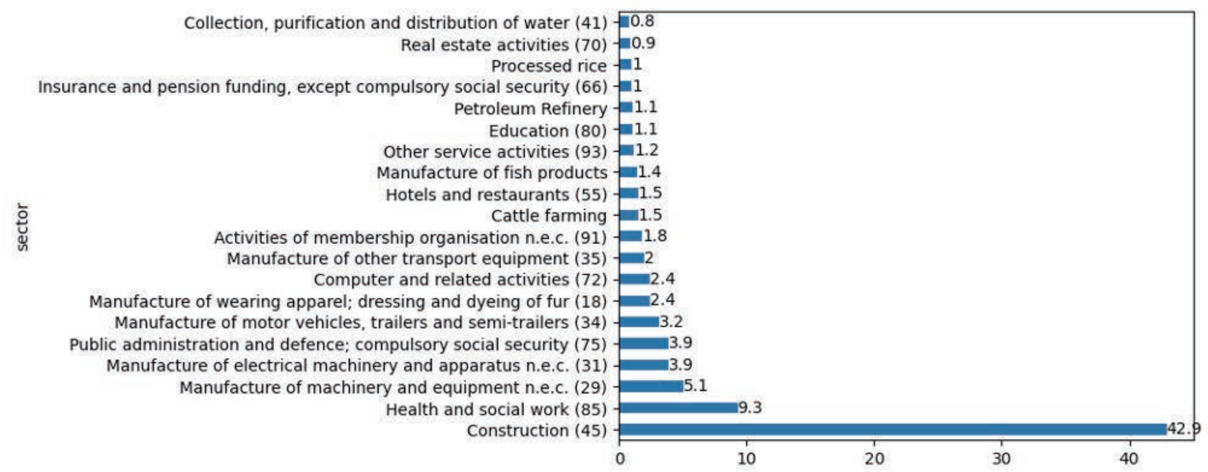
Figure 2: Top 20 sectors contributing to Raw Material Consumption (RMC) of China in percent of total (28.5 Gt/year).



Note: The numbers in brackets denote NACE Rev 1 Division Codes. Refer to Table 9 A for a list of subsectors included in each sector.Source: own research using EXIOBASE v3.8.1

Global Temperature Potential (GTP) was proposed by Shine et al. (2005) and received by the IPCC as an alternative measure for climate change. While GWP is a measure of the heat absorbed over a given time period due to emissions of a gas, GTP is a measure of the temperature change at the end of that time period. Both measures express the effects of climate gases relative to CO2, while GTP includes models of how the climate system responds to increased concentrations of GHGs. Besides its potential advantage of being more strongly related to the earth’s surface temperature change than GWP, GTP was used for lack of available characterization factors for GWP matching the stressors included in EXIOBASE’s Environmental Extensions. Bulle et al. (2019) introduced the IMPACT World+ life cycle impact assessment method, comprising characterization factors for GTP while Agez et al. (2022) compiled a database compatible with EXIOBASE 3. Long term effects at midpoint level were con-sidered for comparibility with GWP as recommended by the authors (Bulle et al. 2019).

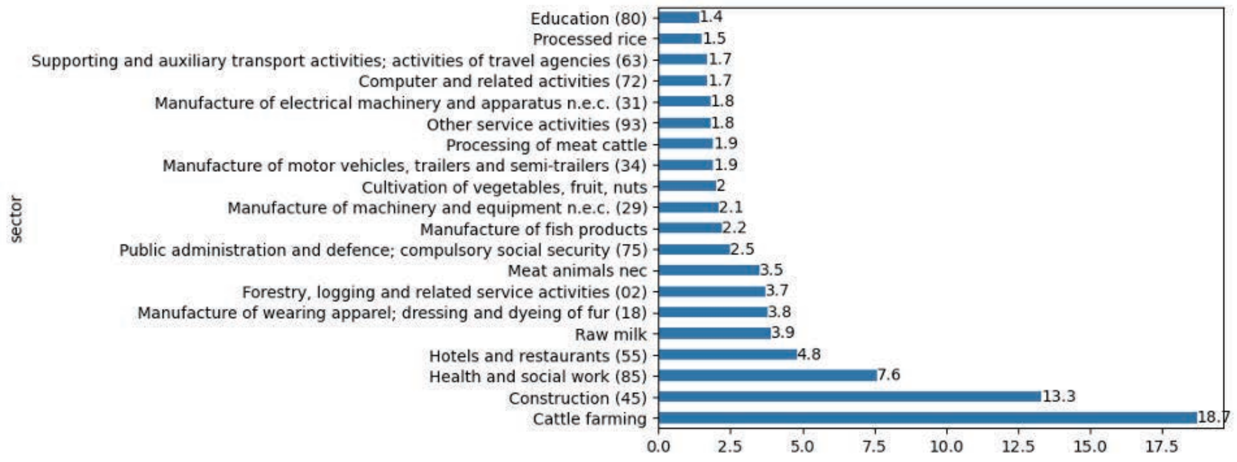
Figure 3: Top 20 sectors contributing to consumption-based Global Temperature Potential (GTP) of China in percent of total (14.6 Gt CO2-eq/year).



Note: The numbers in brackets denote NACE Rev 1 Division Codes. Refer to Table 9 A for a list of subsectors included in each sector. Source: own research using EXIOBASE v3.8.1

The land use footprint is comprised of crop land, forest area, permanent pastures, land occupied by infrastructure as well as a category named 'Other land use' in EXIOBASE 3.8.2. Unlike GTP, it is not characterized by a characterization factor but merely the sum of square kilometres of land oc-cupied domestically and internationally. Analogously to Figure 1 and Figure 2, Figure 3 shows the amount of land used to provide the Chinese final demand by industries in percentages. Note that the total land used exceeds the geographical area of China, which is due to the fact that the land use indicator comprises domestic and international land occupation.

Figure 4: Top 20 sectors contributing to land use (LU) of China in percent of total (17.6 Mio km^2).



Note: The numbers in brackets denote NACE Rev 1 Division Codes. Refer to Table 9 A for a list of subsectors included in each sector. Source: own research using EXIOBASE v3.8.

Interpretation of results of the MRIO analysis

Construction work, the health and social work sector, manufacture of machinery and equipment as well as cattle farming contribute strongly to all of the three impact categories analyzed in this study. The construction sector clearly dominates the RMC and GTP indicators while cattle farming con-tributes most strongly to land use. These results are plausible given both the high impact in terms of material demand and CO_2 emissions and the magnitude of construction work going on in China. However, the direct emissions of passenger and freight transport are not found among the top 20 contributing sectors. A closer look at CO_2 emissions, as a proxy for Global Temperature Potential showed that the railways transportation, inland water transportation, air transport and "other land transport" sectors together emitted around 173 Mt of CO_2 to air. Other literature[7] estimates this value at around 700Mt for China. This indicates that transport emissions were largely ascribed to other sectors, thus blurring the picture and making the transport sector elusive. For example, membership organization services (NACE code 91) contain activities of business, employers and professional organizations, trade units as well as religious and political organizations, all of which may include services of the transportation sector depending on the Chinese system of national accounts. Experts consulted on this topic confirmed the intransparency of EXIOBASE sectors especially with regard to China [8].

[7]Zhang, K., Liu, X. & Yao, J. Identifying the driving forces of CO2 emissions of China's transport sector from temporal and spatial decomposition perspectives. Environ Sci Pollut Res 26, 17383–17406 (2019). https://doi.org/10.1007/s11356-019-05076-3

[8]Personal communication with Monika Dittrich, Wuppertal Institute on 29.05.2024, and with Matthias Pfaff, United Nations Industrial Development Organization (UNIDO) on 29.05.2024

In the EXIOBASE version used in this study, data beyond 2011 is largely based on estimates with some exceptions featuring data from later years. China's Economy has changed and diversified rapidly since then, indicating that results need to be interpreted with care. The compilation of Sup-ply-Use tables (SUTs) often requires some modelling and assumptions which may differ between countries. Thus, while MRIO models are generally justified for the task of macro-scale environmental analysis on a sector or product level, the case of China is especially difficult to assess from an outside perspective. During the creation of EXIOBASE from SUTs, additional assumptions, such as the fixed product sales assumption or the industry technology assumption, as explained in the methods section, are made to deal with secondary industry outputs, i.e. by-products. For this reason, both resulting EXIOBASE systems, "product by product (pxp)" and "industry by industry (ixi)", were compared in this study, yielding similar results.

Consumption-based footprints, like the ones calculated for this study, include, unlike produc-tion-based accounts, the environmental impacts along the supply network that is needed to satisfy the final demand of a country. Consequently, the sector ranking does not present an accurate description of the Chinese economy but rather of the global economy's sectors active to provide for China's consumption. This is manifested, for example, in the definition of RMC which considers both do-mestic and foreign extraction but excludes exports to other countries. In the case of construction, high-impact bulk materials such as cement and steel are usually sourced domestically which should shrink the difference between consumption-based and production-based accounts. Since circular economy strategies do not only target production but also consumption habits, both perspectives are justified. The consumption-based sector perspective outlined in this chapter can therefore be seen as a starting point for further analysis, bearing in mind the inherent uncertainties and the most likely underestimated transport sector.

Annex II Analysis and description of macroeconomic (Top-Down) modelling studies

MRIO data is available but databases with sufficient sectoral resolution are outdated as in the case of EXIOBASE 2015 (Stadler et al. 2018). Thus, recent and ongoing developments in the Chinese economy can only be captured through extrapolation of trends at the cost of introducing additional uncertainty. In these models, final demand can be adjusted according to CE scenarios and their environmental implications can be analyzed on a sector level (Donati et al. 2020). However, in-ter-industry flows and sectoral shifts are difficult to interpret as intermediate industrial products may or may not be captured in the sectoral output to the market depending on the system of national accounting (SNA) from which the IO table is constructed (Pauliuk 2018). Details on the interpretation of results for the Chinese context based on EXIOBASE can be found in Annex I.

CGE models are well suited to examine the effects of policies and new technologies on so-cio-economic variables such as GDP and employment rates. However, they heavily rely on economic paradigms and their built-in assumptions about the behaviour of markets, consumers and producers. Dynamic MFA is arguably the most precise modelling technique in terms of its ability to trace physical material flows and related environmental impacts, but it also has a high demand for data. In practice, analyzes will need to restrict to certain materials, which can then be traced rather accurately. Broader economic implications are usually not captured.

Integrated assessment models often combine several of the above model classes and provide possibilities for long-term analysis in line with socio-economic narratives. On the downside, IAMs are complex, computationally expensive, and often lacking in transparency (Gambhir et al. 2019).

For assessing the feasibility of a comprehensive CE modelling, the following macroeconomic modelling studies and their respective data basis for China were analyzed.

Table 2: Macroeconomic modelling studies and their data basis for China

Oeko-Institut (2023)	**Modell Deutschland Circular Economy (Circular Economy Model Germany – Modelling study)**
Regions covered	Germany (for gross value added and workforce requirements and security of supply); Global (for environmental impacts: GHG emissions, resource use and land use/ biodiversity).
Sectors covered	Building construction; Civil engineering; Vehicles and batteries; Information and communication technologies (ICT) and household appliances; Food and diet; Textiles; Packaging; Furniture; Lighting.
Summary of results	The comprehensive CE measures modelled in the Circular Economy Model Germany result in substantially positive environ-mental impacts compared to the Continue-as-Planned scenario by 2045: GHG emissions: Reduction by an additional 186 Mt CO2-eq globally (–26%); reduction of 10% compared to 1990 levels (addi-tional) or 26 Mt CO2-eq of hard-to-avoid process emissions from steel, cement and ethylene production. Resource use: Reduction in RMC –179 Mt (–27%) or TMC –329 Mt (–26%). Land use: Additional reduction of 8.5 million hectares of land; this corresponds to 25% of Germany's total area. Biodiversity: Reduction in the potential loss by 32% in the food sector. In addition, there are positive effects on supply risks, freed-up income and health. Depending on how freed-up income is spent, gross value added and labour needs profit as well: Alleviation of supply risks: Alleviation of supply situation for 29 out of 36 raw materials analyzed; more than 50% of demand for pal-ladium, yttrium, dysprosium, neodymium, terbium, cobalt, copper, praseodymium and gallium is met by the measures; 8 of these raw materials are already classified as critical by the EU today. Freed-up income: EUR 170 billion. If primarily spent in the ser-vice sector: Gross value added: increase by 14% or EUR 483 billion Labour needs: increase by 11%. Increase in the percentage of female workers as a result of an increase in work in the service sector. Health: Improvement of human health due to the reduction in air and environmental pollution.
Description of model used	The study used a hybrid model approach, combining Multi Regional Input-Output (MRIO) analysis, Life Cycle Assessment (LCA), Mate-rial Flow Anaysis (MFA) and Industry Simulation Model FORECAST. The MRIO was applied using EXIOBASE v3.8.1 in conjunction with the python package 'pymrio'. For the purpose of this study, the 2022 version of EXIOBASE was used. MRIO was integrated with life cycle assessments from the literature in order to check the accuracy of the results and to supplement them from a bottom-up modeling perspec-tive. The bottom-up simulation model, FORECAST, mapped the final energy consumption and direct emissions of the industrial sector and provided information on the contributions of a circular economy to the decarbonization of the German industrial sector.

[9]Different scenarios were modeled in the study. The impacts presented here are those of the most ambitious "Mixed scenario", which includes technical as well as behaviour-based measures. The environmental benefits are lower in the other analyzed scenarios.

Oeko-Institut (2023)	Modell Deutschland Circular Economy (Circular Economy Model Germany – Modelling study)
Assessment of mo-del used	The hybrid model system made it possible to overcome the specific limitations of top-down and bottom-up models and to utilize the strengths of the different models. In this way, the effects of individual CE measures as well as of the examined sectors could be compre-hensively modeled and analyzed with a high level of detail. However, the data basis of the EE-MRIO modeling and the life cycle assessments is based on status quo values. The projections for 2045 therefore refer to current static interdependencies between production sectors and countries as well as ecological and socio-economic parameters. EE-MRIO is an established method in which these aspects are not dynamically adjusted. The response to this was that the changes in demand, e.g. in the electricity mix, electromobility or labor productivity were aligned with the framework parameters of the German climate projection report 2021 and beyond. The detailed modeling in FORECAST decarbonization was addressed beyond the CE measures. Despite the comparatively high-resolution database of EXIOBASE, the modeling of individual sectors and their measures lacked a certain level of detail. The hybrid approach allowed LCA data to be used in selected cases. The analysis was also limited to nine highly relevant sectors, the scope of which, however, is not representative of the economy as a whole and therefore cannot be interpreted accordingly. With the impact models, the sector experts aimed to provide a com-prehensive assessment of the effects and rebounds associated with a measure. The development of the models was accompanied by a reduction in complexity, which was partly due to a lack of data and the resulting limitations in quantifying the effects. Further effects that were not recorded are therefore possible. Despite uncertainties, the rebound income was included in the analysis, as it is otherwise a partial con-sideration that is limited to the effect of the change in demand in the sectors under consideration. An analysis that includes the rebound can lead to a more holistic assessment of the effects of measures. In this way, the Model Germany Circular Economy study provides valuable policy-makers to constantly evaluate legislation and implementation with regard to rebounds. Interpretation of the suitability for the Chinese context is provided in detail in Annex I EXIOBASE Multi Regional Input-Output (MRIO) analysis, under the chapter Interpretation of results of the MRIO analysis.

The World Bank (2022)	Squaring the Circle (Model/Database: GTAP-CE)
Regions covered	Europe (EU countries as well as EFTA countries and the United Kingdom)
Sectors covered	Depends on chapter/analysis. Concerning primary material reductions: fossil fuels, mining of metal ores, non-metallic minerals.
Summary of results	● Combined and comprehensive CE policies can deliver large reductions in primary material use relative to an initial scenario (BAU). ● Growth: CE objectives can be achieved at a relatively small direct cost to the economy. The most ambitious policies considered will reduce 2030 gross domestic product (GDP) by only around 1 percent below baseline projec-tions (while real GDP is still 13.5 percent higher in 2030 compared to BAU in 2021 under an ambitious CE sce-nario). This cost is considered minor compared to the resulting benefits (e.g. concerning environment and health). ● Structural shift: Comprehensive CE policies will accelerate the shift towards services sector economies. ● CE policies are expected to have moderately regressive labor market impacts, which are somewhat attenuated by progressive price impacts. Country-level distributional impacts can be significant. Unskilled workers are more affected by negative changes in real wage or unemploy-ment than skilled workers. ● The use of tax revenues is critical to the outcomes of CE policies, using revenues to reduce labor taxes can lead to growth- and welfare-enhancing outcomes. If revenues created by CE taxes are not redistributed to households but used to reduce labor taxes, this eliminates GDP losses and reverses negative labor effects (with unemployment for both skilled and unskilled workers then falling), while wages rise.
Description of model used	ENVISAGE is a recursive, dynamic, global Computable General Equilibrium model (CGE), calibrated on the GTAP-CE database. GTAP-CE is a specific version of the Global Trade Analysis Projects (GTAP) database, designed to meet the needs of circular economy modelling. The GTAP-CE Database has a geographic coverage of 141 regions. Four sectors from the original GTAP model are further dis-aggregated into 23 subsectors. ENVISAGE uses an aggregated version of GTAP-CE featuring 20 regions (including China) and 42 activities. Scenarios include carbon prices based on Nationally Determined Contributions (NDCs). The baseline scenario incorporates emission reduction policies but no explicit measures for reduction of material use. Other scenarios include taxes on primary materials and subsidies for secondary materials or a combination thereof. Scenarios apply to Europe only. The time horizon is until 2030.
Assessment of mo-del used	General Equilibrium models allow for macro-scale economy wide modelling of how prices, taxes, subsidies and other instruments affect different sectors of the economy. GTAP-CE is generally applicable to China. Biomass is excluded from the analysis.

Agora Industrie; Systemiq (2023)	**Resilienter Klimaschutz durch eine zirkuläre Wirtschaft (Resi-lient climate protection through a circular economy)**
Regions covered	Germany
Sectors covered	Energy-intensive basic materials industries: steel, concrete, cement, plastics
Summary of results	● ergy-intensive industries: The circular economy can achieve climate targets faster, more cheaply and with lower energy consumption. With a combination of decarbonized primary production and circular economy measures in the energy-intensive value chains of steel, cement and plastics, cumulative GHG emissions can be reduced by 25% by 2045, transformation costs cut by 45% and energy con-sumption reduced by 20%. ● Material efficiency and recycling enable new business models and strengthen resilience: they reduce dependence on energy and raw material imports and preserve the value of domestic resources. ● To realize a CE, a wide range of technologies and measures is required, mostly depending on the specific raw material or sector. [Only technological CE measures are modeled, i.e. recycling, more efficient use of materials and longer use of products. Behavior-based CE strategies that include the use of products (e.g. car sharing) are not considered.]
Description of model used	The model focuses on Germany using a consumption-based ap-proach (including emissions outside geographic boundaries) as op-posed to a production-based approach. It comprises four modules: 1.required stock module (automobiles, buildings, packaging) 2.stock and flow module 3.EoL and waste management module 4.production module The time horizon expands until 2045, extrapolation of demand and population trends based on Shared Socioeconomic Pathway 2 (SSP2) fitted to Germany by Pauliuk und Heeren (2021)
Assessment of model used	There is no explicit model description available. Dynamic stock modelling is based on the ODYM-RECC model.

IRP (2020)	**Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future (ODYM-RECC)**
Regions covered	G7, EU28, China & India
Sectors covered	(a) Residential buildings, (b) light-duty vehicles
	Residential buildings: Material efficiency (ME) strategies can re-sult in substantial reductions in the demand for virgin materials and associated GHG emissions. For the modelling, the effects of ME on both material and energy use were incorporated. ● The assessed ME strategies could reduce annual GHG emissions associated with the material cycle of the con-struction of residential housing in G7 countries and China by up to 80 to 100 per cent in 2050 (compared to a scenario without ME). → Savings of 270-350 Mt per year in China in 2050 (plus 70 Mt savings due to reduced need for heating and cooling because of reduced floor space) (Modelled measures: Lighter buildings, using wood instead of reinforced concrete/ masonry, reducing demand for floor space, life-time extension, reuse of building components, improved recycling) ● For the whole building life cycle (including emissions from operational energy use) the ME strategies could reduce emissions from the construction, operation and decon-struction (dismantling) of homes by 35 to 40 per cent in the G7 and by up to 50 to 70 per cent in China and India. The reductions could be achieved quickly and are not dependent on the development of new technologies. Light-duty vehicles: ● Compared to a scenario with no new ME strategies, the modelled strategies can save up to 25 Mt CO2e per year from the material cycle of vehicle production and disposal in 2050 in the G7 and 25-30 Mt per country in China and India. ● Synergistic emission reductions associated with reduced operational energy use are 280-430 MtCO2e per year in the G7 and 240-270 Mt per country in China and India. (Modelled measures: higher yields in manufacturing, reuse and recycling; smaller, lighter vehicles; material substitution; more inten-sive use e. g. through car-sharing and ride-sharing) Note: Emission reductions arising from ME are estimated by comparing scenarios with and without the implementation of different ME strategies. Therefore, the reduction quantified in this report is in addition to reductions achieved through the assumed decarbonization of the energy supply and the shift towards electric vehicles.
Description of model used	Dynamic Material Flow Analysis, macro-scale prospective LCA, Model parameters tuned to match Shared Socioeconomic Pathway narratives
Assessment of model used	ODYM-RECC is open source and well documented. It features accurate and comprehensive data collected from different, reputable sources. Economic layers are not yet included and infrastructure and industrial assets are not covered. The model has high data demands and is therefore currently confined to certain services (individual transport and shelter). However, other services such as public and freight transport will be included in the future. Its time horizon expands until 2060 and it is generally suited for application with China. The authors state that: "the ODYM-RECC model, including the link to the different product archetype descriptions, represents a major advancement in prospective modelling of the economy, as it consistently integrates the service, product and material perspectives down to the individual chemical element; works in a multi-regional setting at full sectoral scale; and combines a large variety of data in a consistent manner. Consistent data on the energy consumption and material composition of the product archetypes for buildings and vehicles used were obtained from widely used high-resolution model platforms for buildings and vehicles (accurate down to the individual component)." IRP (2020).

UNEP (2024)	Global Resources Outlook 2024: Bend the Trend - Pathways to a liveable planet as resource use spikes
Regions covered	Global
Sectors covered	Two scenarios are defined: ● "Historical Trends" (HT): business-as-usual scenario, with established resource use patterns continuing (mod-elling does not fully include negative effects of environ-mental impacts on economy & well-being) ● "Sustainability Transition" (ST): assesses the impact of the implementation of socially and technologically feasible shifts: (a) resource efficiency (b) climate & energy (c) food & land (d) just transition
Summary of results	Measures of the ST scenario lift global economic performance and boost economic growth and well-being, while decoupling growth in incomes and resource use from environmental impacts. Income and well-being improve, urgent pressures and impacts fall significantly (other pressures stabilize or moderate. Decoupling outcomes and patterns vary across income groups). ● All four key pressure indicators grow less than they do under HT (2060 compared to 2020): ● Resource extraction and use grows more slowly than economic growth (relative decoupling). Total global re-source extraction is 20% above 2020 levels in 2060, rather than 59% under HT. Food and fibre biomass extractions increases 40% rather than 79%. Primary energy supply falls by 27%, in contrast to the 41% increase in HT. The area of agricultural land falls by 5% rather than rising by 5%. ● One key impact indicator – greenhouse gas emissions – improves, with emissions falling by 83% from current levels (absolute decoupling). ● Other key impact indicators show relative decoupling, with Towards Sustainability avoiding 38% of the biodiversity loss projected under HT. ● ST finds higher HDI (Human Development Index) values for all income groups: up 5.8% and 6.8% for upper and lower middle-income nations, and up 11.5% for low-income nations, relative to HT. ● Combining action on resource efficiency, energy and climate plus food and land, achieves significantly greater positive effects than isolated packages.
Description of model used	Combination of four model types: IMAGE is an Integrated Assessment Model (IAM) which allows modelling the consequences of socio-economic activities on the global environment. IMAGE identifies scenarios in line with the Shared Socio-Economic Pathways (SSP) narratives and with Representative Concentration Pathways (RCP). For the GRO24 it is used for producing results for energy use and greenhouse gas emissions. IMAGE-MAT is an extension of IMAGE for material stocks and flows. It is used for results on materials use, energy and emissions from buildings and transport. GTEM (Global Trade and Environmental Model) is a Computable General Equilibrium Model estimating economic outcomes on a macroeconomic and sectoral level including, for example, shifts in industrial GHG emissions from policy and technological change sce-narios. It can also provide material use projections by sector, region and material. In GRO24 it is used for results on economic activity and total resource use. GLOBIOM (Global Biosphere Management Model) is a dynamic partial equilibrium model for land use including agriculture, forestry and the bioenergy sector. It's spatially explicit results are used for land and food variables. Time horizon: up to 2100
Assessment of mo-del used	State of the art, comprehensive large scale model; links between individual sub models ensure consistency of assumptions and results. Possibly not fine-grained enough for an explicit assessment of China; modelling framework designed to model global/macro-scale interactions

Circle Economy (2023)	The Circularity Gap Report 2023
Regions covered	Global
Sectors covered	(1) Food system (2) built environment (3) manufactured goods and consumables (4) mobility and transport In total: 16 measures (4 per sector)
Summary of results	If a circular economy was implemented across the four analyzed global systems, virgin material extraction could drop by 34% (from 92.7 billion to 61.2 billion tons). In addition, the current overshoot of five planetary boundaries could be reversed: ● Climate change: From 191% above the boundary to 46% above the boundary (enough to limit temperature rise to 2-degrees) ● Land system change: From 47% above to 143% below the boundary ● Nitrogen cycle: From 59% above the to 3% below the boundary & phosphorus cycle: From 33% above to 14% below the boundary ● Ocean acidification: From 13% above to 43% below the boundary (+ Freshwater use from 59% to 62% below the boundary and aerosol loading from 87% to 93% below the boundary) Different strategies are defined for shift countries (high-income, score high on HDI), grow countries (largely middle-income, typically global manufacturing hubs and big agricultural producers, e. g. China) and build countries (score low on HDI).
Description of model used	The Circle Economy model uses a hybrid approach of top-down methods from the Industrial Ecology 'toolbox' combining economy-wide material flow accounts (EW-MFA) and Environmentally-Extended Multi-Regional Input-Output Analysis (EE-MRIO) Data sources include: ● EXIOBASE ● EU-MFA questionnaire according to European Commission (2018) ● National Statistical Institutes (NSIs) ● International trade in goods statistics (ITGS) from COMEXT or BACI ● Physical or hybrid supply and use tables (PSUTs/HSUTs) ● Eurostat waste statistics The temporal scale is for individual years between 2018-2024
Assessment of model used	The Circle Economy model is well-grounded in Industrial Ecology methods and uses up-to-date, reliable data sources. Documentation is transparent and quantitative indicators are well defined The applicability to China depends on data availability. Here, it is difficult to make ad-hoc statements and a detailed data screening will be necessary.

Deloitte (2021)	Zirkuläre Wirtschaft: Herausforderungen und Chancen für den Industriestandort Deutschland (Circular economy: Challenges and opportunities for Germany as an industrial location)
Regions covered	Germany
Sectors covered	Ten raw materials: Steel, lead, copper, aluminum, other non-ferrous metals, paper, glass, plastics, building materials and wood. The focus of the analysis is on the substitution of primary raw materials with secondary raw materials. Other aspects of the circular economy (e. g. lower material usage and longer service life) are not considered. Selected experts from associations and companies were asked to estimate the substitution potential of the most important primary raw materials with recycled secondary raw materials (by 2030). The values determined were fed into a global macroeconomic input-output model in order to simulate the effects.
Summary of results	If the substitution potential estimated by experts is exhausted, the following results emerge: ● Gross Value Added: ca. +12 billion euro (5 billion euro are direct effects related to the recycling industry, 7 billion euro are indirect effects related to upstream and down-stream industries) ● Employment: +180,000 jobs (71,000 direct/106,000 in-direct) ● Import dependency: The German economy will become less dependent on imports. For aluminium, glass, and lead ca. - 20 % for each material. ● Reduced demand for primary raw materials: metal ores -8.7 Mt, non-metallic minerals -4.7 Mt, fossil fuels -3.9 Mt, wood -1 Mt. ● Reduction of GHS emissions: -5.5 Mt CO2e globally (these are the net effects, in Germany, emissions will rise by 8.9 Mt CO2e e. g. because of augmented recycling processes, but globally they will sink by 14.4 Mt CO2e) (Model assumptions: same prices for respective primary and secondary raw materials, substitution of reduced imports by secondary raw materials recycled in Germany.)
Description of model used	The study applies Multi-Regional Input-Output Analysis using EXIOBASE. Projected demand for primary and secondary materials by different sectors was manipulated based on expert judgement and the resulting emissions were calculated. The time horizon expands until 2030.
Assessment of model used	The model has a narrow focus on only one CE strategy namely increasing the shares of secondary materials and, unlike most other models scrutinized in this study, does not combine different modelling approaches. If using MRIO as a standalone method, its inherent uncertainties propagate to the model results which then require particular care in their interpretation.

OECD (2018)	The Macroeconomics of the Circular Economy Transition – A Critical Review of Modelling Approaches
Regions covered	Meta-study, regions vary among the studies examined. The geographic coverage for multi-regional models ranges e. g. between 5 and 39.
Sectors covered	Meta-study (sectors vary among the studies examined).
Summary of results	Four key conclusions: ● Most models find that a transition to a more circular economy could have an insignificant or even positive impact on aggregate macroeconomic outcomes. ● All models highlight the potential re-allocation effects – both between sectors and regions. ● Certain types of macroeconomic models are more ap-propriate than others: Dynamic, economy-wide mul-ti-region models are best suited to capture the transition in the economy, as well as socioeconomic trends and trade impacts. ● The assumptions that are fed into the models are crucial for the model outcomes (e. g. concerning future rates of productivity growth, substitutability between different material types, future consumption patterns). ● Macroeconomic effects: ● GDP: The majority of studies show (partly significant) positive effects, few show significant negative effects (-1.6 % to +15 %) ● Resource extraction: The analyzed studies suggest that the implementation of circular economy policies can reduce resource extraction by up to 80% (results between ca. 0 % and 80 %). They also highlight the existence of a trade-off between higher rates of economic growth and lower re-source extraction (i.e., that CE strategies that have a par-ticularly positive effect on economic growth hardly reduce resource extraction and strategies that reduce resource extraction particularly strongly have a less positive effect on economic growth). Important: The results of the studies depend to a large extent on the models used and the assumptions made (e.g., assumed policy in-struments, rate and costs of changes in technology and preferences, use of the additional tax revenues through material taxes, employment of single measures or policy packages).
Description of model used	n.a.
Assessment of model used	n.a.

Annex III Trends, best practices, and barriers for a CE in additional relevant sectors

Table 3: Trends, best practices, and barriers for a CE in additional relevant sectors

	Construction
Trends/ Hot topics	● China's urbanization trend has an unprecedented rate, creating substantial demand for new housing and infrastructure. In 2016, the built area under construction and completed built area represented half of the world's new construction; and by 2030, China's urban population will reach one billion (EMF 2018). ● Buildings are not designed for durability or flexibility. The average lifespan of a building in China is 25–30 years, as construction firms tend to adopt low-quality materials to reduce the total cost of buildings. This has led to several building collapse tragedies in Shanghai, Nanjing, and Wuhan (EMF 2018). ● High consumption of primary materials (e.g. China produces and consumes around 55% of cement globally), which leads to significant greenhouse gas emissions, China now being responsible for more than 18% of total CO_2 emissions in the global building sector (having surpassed the EU in 2011) (EMF 2018). ● In China, about 2.36 billion tons of construction and demolition waste (CDW) were produced annually (during the period of 2003-2013) due to fast-advancing urbanization (Zheng et al. 2017), accounting for 30 to 40% of the total amount of waste in the country (Huang et al. 2018). ● Most of the CDW generated in China is piled up in rural areas or simply landfilled (Li et al. 2018). Only about 5% is recycled or reused (Huang et al. 2018). Furthermore, most of this percentage is reused for road gravel rather than reentering the construction industry. Meanwhile, the dumping of toxic CDW causes soil, water and air pollution (EMF 2018). ● For many cities in China, material recovery is not normally carried out by the local authorities or landfill operators due to low recovery value (Zheng et al. 2017). ● However, according to Jin et al. (2017), recent movements from both governmental regulations and industry implementation in China indicate the ongoing trend of technical standard development for waste diversion. For example, in the provincial level, the Zhejiang Green Building Regulation encourages the use of recycled building materials; and in the municipal level, the Chengdu government announced a recycled content policy for all government-funded projects.
Barriers	● Lack of legislation, e.g., no national or local regulation to guide the disposal of CDW via landfilling, and no specific regulations on sorting and safe treatment measures for non-inert or hazardous CDW debris (Zheng et al. 2017). ● Primary barriers to reducing CDW in China include: Lack of building design standards, low costs for CDW, and inap-propriate urban planning. Most existing regulations target treatment rather than reduction of CDW, and few regulations require CDW reduction during the architectural design stage (Huang et al. 2018). ● Primary barriers to reusing CDW in China include: Lack of guidance for effective collection and sorting, lack of knowledge and standards for reused CDW, an un-der-developed market for reused CDW products (Huang et al. 2018) ● Primary barriers to recycling CDW in China include: Inef-fective management system, immature recycling technology, an under-developed market for recycled CDW products, and immature recycling market operations (Huang et al. 2018). ● Lack of client demands was identified by Jin et al. (2017) as one of the main difficulties in CDW diversion. Their study revealed that "engineers and consultants had a more positive perception on promoting industrial training in CDW recy-cling, while construction management professionals held more conservative opinion on it".

	Construction
Barriers	● The preservation and continued use of existing buildings and infrastructure do not take precedence over resource- and space-intensive new construction. This means that the gray energy used for construction and stored in the building materials is lost. ● As there is hardly any awareness of reuse, deconstructability and recycling during the construction of buildings, it is often not possible to provide unmixed material flows from the secondary raw material store, or usually only at great ex-pense. ● The construction or maintenance of structures and buildings is partly carried out using materials that are now considered pollutants and must be reliably removed from the material cycle. However, there is generally insufficient information available on the materials and substances used.
Best practices	● Design for longevity, incl. modular, flexibel, and durable design. ● Industrial manufacturing of standardized and modular building components, combined with on-site assembly (EMF 2018) ● Green, smart, energy-efficient buildings; e.g., passive houses. ● Reuse and recycling of CDW, incl. urban mining, selective and unmixed recovery of raw materials from buildings, and targeted removal of pollutants. ● Use of secondary materials, and development of building materials and processes to replace increasingly scarce and ecologically and geopolitically questionable raw materials. ● Resource-efficient, low-greenhouse gas and circular binder technologies, including the reduction of the CO2 footprint of cement.
	Textiles
Trends/ Hot topics	● China accounted for 55% of worldwide textiles production in 2014 and generated 70% of the world's synthetic fibres. Not only is China "the world's largest fibre producer, but it is also the world's largest textiles exporter, and the largest textiles machinery manufacturer" (EMF 2018). ● China's rapid economic growth and urbanisation coupled with growing middle class, "tripled the domestic demand for textiles and will grow threefold yet again over the next decade" (EMF 2018). ● On one side, urban citizens are accelerating the shift towards fast fashion; it is predicted that, by 2030, China's clothing sales (currently 6.5 kg) may rise to 11-16 kg per person, bringing China in line with North America (EMF 2018). ● On the other side, affluent citizens are increasing the demand for quality and branded luxury goods, with "preferences shifting towards more value-added products, 'green' products, personalisation, innovation, better quality and services" (EMF 2018). Overall, linear 'take-make-dispose' approach to production and consumption of textiles. ● Relocation of textiles manufacturing plants from the east of the country to western and central regions, to counteract rising wages and production costs (EMF 2018) ● 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", i.e. increased share of technical textiles by 4.6% between 2010 and 2014 (EMF 2018). ● E-commerce trends; "one of the online categories with the highest adoption rates is garments, with an online shopping adoption rate of almost 60%" (EMF 2018). ● Textile waste (20–26 million tons annually) resulting from increased production and fast fashion. Due to China's waste-processing capacity being unable to cope, with land-fills in large cities running out of space, the government is now stimulating measures such as recycling (EMF 2018). ● Water depletion: the textiles industry has now become the country's third largest water consumer, using approximately three trillion litres each year (EMF 2018)

	Textiles
Trends/ Hot topics	● Water pollution due to textiles dyeing and other treatment processes causes. The heavy use of chemicals "has led to the textiles and garment industry being ranked the sec-ond-largest contributor to wastewater chemical oxygen demand (COD) pollutants in China" (EMF 2018). However, most of the research during the last decade has focused on textile wastewater treatment (Huang et al. 2021).
Barriers	● The prevailing market conditions and the cost structure: short-life textile products are predominantly imported by bulk buyers from countries with lower labor costs and low labor and environmental standards and offered at low prices (Dudin et al. 2015). ● Excessive focus on the export sector, and the lack of ef-fective control of the import-export of textile raw materials and products (Dudin et al. 2015). ● Enteprises lack own financial resources, lack of access to bank loans, which are necessary to upgrade manufacturing (Dudin et al. 2015). ● Circular business models are largely unable to compete with this global supply market. ● Low prices for new goods, short-lived designs and limited willingness or ability to repair textiles and use second-hand goods (low social appreciation of textiles). ● Lack of incentives for technical innovation and investment at the end of life of textiles: A lack of take-back systems and low economic efficiency in the sorting, reuse and recycling of textiles hinder the optimization of the collection, collec-tion and recycling of used textiles. ● Lack of circular design
Best practices	● Design for durability: Longer-lasting and repairable textiles. ● Product-as-a-service: Business models that increase utili-zation of durable textiles (sharing, renting, leasing), in-cluding technical textiles in B2B markets. ● Reverse logistics: Collection or take-back logistic systems . ● Fiber-to-fiber recycling. ● Reduction in the number of garments produced. ● Resource efficiency in the supply chain: Automation and 3D printing, efficient water and energy management, water re-cycling and treatment.
	Hotels and gastronomy
Trends/ Hot topics	Hotels: ● In China, the domestic tourism market grew steadily from 2010 to 2019. In 2010, the number of domestic tourists was just over 2.1 billion and by end of 2019 it had exceeded 6 billion (Poshan Yu et al. 2022). ● The hotel industry of China is among the fastest growing in the world, with hotel franchising becoming the most popular form of expansion. The number of hotel rooms is expected to increase to 6.3 million (estimated at 2.5 million in 2015), which would double the number of rooms per thousand inhabitants (Ž. Đorđević und Janković 2015). However, "it seems that the hotel industry is facing problems in this large emerging market, partially due to an over-supply of hotels" (Yang und Cai 2016). ● Increased appetite from tourists for accomodation and more authentic travel experiences has fostered the growth of property-sharing platforms (EMF 2018).

	Hotels and gastronomy
Trends/ Hot topics	Gastronomy: ● China's urban nutrition patterns are shifting towards in-creased consumption of animal protein; "the average Chi-nese 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, with beef consumption making up 10% of that increase" (EMF 2018). ● Food consumed outside home in China represents 20% of consumption but 30 to 40% of total food waste, due to purchasing and eating habits of the new mainstream con-sumers. Kitchen losses also contribute (EMF 2018). ● China has the largest takeaway food market in the world, representing more than a quarter of the Chinese catering industry and growing rapidly. In 2020, there were 17 billion orders and 0.5 billion consumers in China (Zhang und Wen 2022). The unprecedented plastic packaging use related to this industry results in serious plastic pollution, increasing emissions of plasticizers or phthalate esters (PAEs) and greenhouse gases. While the takeaway food industry gen-erated 1.6 million tons of plastic waste in 2020 (Zhang und Wen 2022), Zhang et al. (2023b) predict it will consume 40.6 million tons of plastic in 2060. ● The online-to-offline (O2O) food market is "a booming industry in China, the market scale of O2O food industry is increasing with remarkable speed. More than 1/5 of total population in China has already became the users of O2O food delivery market" (Zhao et al. 2021a; Maimaiti et al. 2018).
Barriers	● Vatansever et al. (2021) found that the most important transition barriers to circular economy in the tourism in-dustry are: Organizational structure/infrastructure that cre-ates inconvenience with the supply chain, high initial in-vestment costs and/or low returns, lack of corporate social responsibility, additional human resource needs, and lack of awareness/ preferences of the consumers. However, these are in general terms and do not speak specifically for the Chinese context. ● Regarding plastic pollution from the Chinese takeaway food industry, Zhang and Wen (2022) described regional dif-ferences and insufficient research across regions as a barrier to tackle it; "the variety, weight and market share of take-away food packaging products are unclear, which poses an obstacle to recognize the environmental pressure accurately and carry out plastic pollution control methods based on local conditions". ● Lack of targeted and regionally differentiated plastic pollu-tion control policies make it difficult to control the envi-ronmental impact of takeaway food industry (Zhang et al. 2023b). ● Poor supply chain management, pressure to maintain food supply to cater to extensive menu options, and a lack of staff training and education in the gastronomy sector (EMF 2018).
Best practices	Hotels ● Environmental management and monitoring systems ● Resource-efficient hotels: reduced energy and water use, reduced carbon emissions and waste ● Bed linen reuse programs ● Avoidance of single-use products incl. water bottles and mini toiletry bottles ● Use of green cleaning products Gastronomy ● Plant-based meals, or meals with alternative protein sources (e.g. insects) ● Meal preparation following the Planetary Health Diet guidelines ● New restaurant concepts with flexible portion sizes, and that promote quality over quantity and encourage customers to take home leftover food. ● Redesigning and planning menus to reduce waste by reusing leftover food for other plates, reducing the number of op-tions, and using food distribution networks and sharing platforms. ● Use of technologies to achieve waste reduction in institu-tional and restaurant kitchens.

	Metallurgy
Trends/ Hot topics	● In China, the CO2 emissions of the metallurgical industry continually increased during 2000–2015 and reached around 3200 million tons in 2015 (Lin und Xu 2018). CO_2 emissions from China's iron and steel industry account for 51% of total metal industry emissions worldwide (Hu und Zhang 2015). ● The production of crude steel in China has grown from 95.36 million tons in 2000 to 782 million tons in 2013, representing an average annual growth rate of 17.57% (Hu und Zhang 2015). ● Due to the acceleration of urbanization and industrialization and the upgrading of the consumption structure, the total demand for main metal resources will stay high, and the demand for rare metal resources for the technology rev-olution and high-tech emerging industries will continue to increase, with foreseeable severe resource and environ-mental constraints (Feng et al. 2019). ● The extensive growth of China's metal industry constitutes a serious threat to its metal resources security and ecological security (Feng et al. 2018). ● In regard to energy consumption, China's factories are nearly 20 to 40% more consumptive than those of other countries, not to mention that the recycling rate of waste heat and energy in most Chinese steel enterprises was lower (30 to 50% in comparison to Japan's 92%, for example). Moreover, in 2012, most steel produced in China was made using the converter-method, while only 10.2% of the total 716.5 million tons was created using electric furnaces (Hu und Zhang 2015). ● In an analysis of the CO2 emissions performance of the metallurgical industry, Lin and Xu (2018) found that technological progress change was the main factor contrib-uting to the impr
Barriers	● Limited amount of scrap metal for recycling available in China (Hu und Zhang 2015). ● The recycling of metals varies greatly. For some metals, well-functioning material cycles have existed for a long time. For other metals, especially technology metals, the end-of-life (EoL) recycling rate is often less than 1%. The metals field of action is very heterogeneous. ● The potential environmental benefit of metal recycling de-pends on the metal and the specific application or waste stream through which the target metal is recycled. For ex-ample, the production of secondary copper from construc-tion waste generates around three times more CO_2 than production from cables and is therefore not always envi-ronmentally favourable compared to primary production. ● Many metals, especially critical or strategic metals, are only used in low concentrations, making recovery difficult. ● The large number of different steel and aluminium alloys that are mixed together in the collection of scrap makes it difficult to reuse the recovered secondary raw materials in the production of high-quality wrought steel and aluminium alloys. ● Lack of information about which alloys are used in which components/products. ● Multi-stage analysis and sorting processes exist, but are not used across the board because the economic viability of the more complex recycling processes is often not given. ● Greater separation and pre-shredding/manual treatment would also improve the quality of scrap, but is also asso-ciated with higher costs.

	(Manufacture of) vehicles and batteries
Trends/ Hot topics	● The private car stock in China is expected to continue to grow, its saturation level not yet being reached (Gan et al. 2020). The stock of electric vehicles is significantly growing as well (Statista 2024). ● Possible restrictions on the sale of fuel cars, as introduced by some cities in China (Gan et al. 2020; Liu et al. 2020a). Such restrictions could reduce the current growth of the car stock in China (Gan et al. 2020). ● China could achieve a circular battery value chain (and in-dependence from primary raw materials) for lithium, nickel and cobalt much earlier than the US and the EU, driven by "the rapid electrification of the automotive market, the focus on LFP as the dominant battery technology, and an expected early industrialization of non-lithium-containing chemis-tries" (Wesselkämper et al. 2024). Reduction of metal supply risks (apart from lithium) can be achieved by co-balt-free battery technology in combination with efficient recycling systems (Hu et al. 2024). ● The supplementary capacity of second-life EV batteries may be useful for China's prospective novel energy storage ap-plications (Hu et al. 2024). But Wesselkämper et al. (2024) argue that there is a conflict between circularity and a longer product life, so that the advantages of a second use must be evaluated depending on the prioritization of objectives. ● In an effort to combat the issue surrounding congestion and pollution, China's cities are implementing policies that constrain passenger vehicle ownership and use (EMF 2018). Policies concerning vehicle manufacturing were also successfully introduced (Ellen MacArthur Foundation 2022). ● Change in customer attitudes concerning car ownership and more positive attitude towards shared mobility (mostly in urban areas) (EMF 2018).
Barriers	● The switch from combustion engines to battery electric vehicles poses new challenges for the treatment and recy-cling infrastructure and capacities. In macroeconomic terms, this transition will lead to lower primary raw material re-quirements due to the reduction in fossil fuels. In the area of vehicles/batteries, however, there will initially be a strong demand for critical and strategic metals in particular. ● Cars are becoming ever larger and heavier, both in terms of combustion engines and electrically powered vehicles. There are few incentives to include ecological assessments in the design of vehicles. ● The recycling rate of end-of-life vehicles is low. In 2018, the recovery rate of end-of-life passenger vehicles was less than 18% of the scrapped amount (Liu et al. 2020c).
Best practices	● Design for circularity, i.e. "to be remanufactured, fit into shared and multi-modal systems, and to be modular and, therefore, easily adapted" (EMF 2018). ● Product-as-a-service: alternative business models (car sharing, leasing, etc.). ● Second-life batteries and their use for applications such as stationary energy storage (Thakur et al. 2022; Wu et al. 2020).

	Plastics/Packaging
Trends/ Hot topics	● China is the biggest manufacturer, user, and exporter of plastics in the world. The average annual growth rate of China's packaging production was 8.7% between 2018 and 2020. Of the 60 million tons of plastic waste generated in 2020, of which approximately 35% were landfilled, 37% incinerated, and only 26.7% recycled (EMF 2022). ● A CE for plastic is relevant for China's plastics objectives as well as carbon emission and broader environmental goals (EMF 2022). In the 14th Five-Year-Plan, China set the fol-lowing objectives for the plastics sector: (1) Reduce sin-gle-use plastic production and consumption at source, (2) Improve plastic waste collection and recycling, (3) Establish the whole chain management system of plastic pollution, (4) Reduce plastic waste leakage (EMF 2022). ● China has gradually realized policies concerning plastic pollution since the 1990s, although gaps remain (EMF 2022). Especially since 2016 the attention paid to plastics increased significantly, with a major focus on prohibitive bans and information campaigns. Economic policy in-struments, especially economic incentives, have only re-cently started to become popular. In the last years, a di-versification of policy instruments used, plastic types tar-geted and aspects of the value chain considered can be observed as well as a clear intention to build a circular plastic value chain (Fürst und Feng 2022). ● A stronger regulatory focus on plastic cleanup initiatives is expected in the next years (aiming at reducing the leakage of plastics in the environment, especially in the oceans) (Fürst und Feng 2022). ● There is a trend to the use of biodegradable plastics, which is not without problems (Greenpeace East Asia 2020). ● There are a strategy and an initiative aim to promote bamboo as a substitute for plastic (The State Council of the People's Republic of China 2023b). ● Due to the boom in e-commerce and (food) deliveries, packaging waste has increased significantly. This sector has therefore been the focus of several studies and political measures (Liu und Liu 2023; Yang Yuchun et al. 2023; Yang et al. 2024). Other key policy focuses were agricultural plastic film as well as marine litter and microplastics (Liu und Liu 2023).
Barriers	● Policies and standards for the packaging value chain are currently mostly voluntary, siloed or overlapping. Stand-ards should be harmonized and adopted (e. g. under the current discussions on eco-design). Gaps remain (EMF 2022). ● A circular concept for the plastic packaging industry is not fully integrated within current policy initiatives (e. g. Ze-ro-Waste Cities initiatives or waste sorting schemes) (EMF 2022). ● So far, the focus was mostly on downstream measures (like recycling) and not on upstream measures (e. g. solutions to avoid waste) (EMF 2022; Fürst und Feng 2022). ● In some fields there are regulations in force, but there is a lack of implementation and penalty (e. g. for SUPs used in food delivery; Lu 2024).
Best practices	● Internationally, there are many strategies for the elimination, reuse and circular design of plastic packages, e. g. removing of unnecessary parts, deposit systems or use of recyclable and secondary materials (Ellen MacArthur Foundation 2020). ● A Chinese reuse example: Huidu reusable e-commerce boxes (EMF 2020). ● Deposit systems for disposable PET beverage bottles (Germany) ● Quotas for recycled content (e. g. for beverage bottles in the European Union; European Parliament 2024) ● Pledges of local brands to achieve 100% reusable, recyclable or compostable packaging (in China e. g. Nongfu and Mengniu pledge to achieve this goal by 2025) (EMF 2022).

	Electric and electronic equipment and machinery
Trends/ Hot topics	● E-waste is a fast growing waste stream in China, with a forecast average annual growth rate of 10,4% (for computers, mobile phones and other electronics) (Greenpeace East Asia 2019). ● More formal recycling of e-waste could lower carbon emissions and other environmental impacts, reduce dependence on raw material imports and reduce costs for materials like gold (costs for extracted gold are only 35-80% of the costs of virgin mining). China's po-tential for recycling is huge (Greenpeace East Asia 2019). ● Although a formal recycling sector was established, there is still a certain amount of informal recycling activities (Sun et al. 2022). ● In the last years, platforms for secondhand products emerged and China's secondhand e-commerce market showed a growth rate of around 20% in 2022. This might show a shift in consumer attitudes (People's Daily Online 2024). ● The improvement of the fund based EPR system in place in China is currently the object of several studies (Zhang et al. 2023a; Liu et al. 2020b; Wang et al. 2022b; Zhang et al. 2020; Tian et al. 2022). ● The revenue of the Chinese data center market is expected to grow by 7.68% per year (CAGR 2024-2028) (Statista 2023), so data centers might be a relevant topic for a CE as well.
Barriers	● The fund-based EPR-system introduced in China has brought many benefits in the last ten years (Sun et al. 2022). Nevertheless, chal-lenges like the regulation of the level of fund levies and subsidies (Zhang et al. 2023) and the promotion of eco-design remain and consumers awareness and willingness to dispose of EEE appro-priately may be enhanced (Sun et al. 2022). ● Recycling rates for some products are still low (e. g. in 2020, sets of recycled WEEE were 48%, 14%, 20%, 10% and 8% for TV, re-frigerator, washing machine, computer and air conditioners (Lee et al. 2022). ● In the last years, the Chinese WEEE regulation substantially im-proved recycling, but higher levels of the waste hierarchy were receiving less attention (Wang et al. 2021a).
Best practices	● Ecodesign regulations (e. g. on EU level; concerning aspects such as durability, reusability and reparability, recycled content, and in-formation obligations) ● Tax adaptation: lower taxes for repairs (e. g. Belgium, Austria) ● Repair bonus for consumers (e. g. in France where it is financed through a EPR-scheme or in Austria) ● Stronger involvement of manufacturers in the WEEE management system (e. g. in EU) and quantitative recycling targets (Lee et al. 2022). ● Fees based on eco-modulation (suggested in Lee et al. 2022) ● Encourage new business models ● Promotion of reuse stores (sometimes in combination with specific reuse labels like in "De Kringwinkel" (Belgium))

	Health sector
Trends/ Hot topics	● • The Chinese health care sector produced 2.7% of China's total GHG emissions in 2012. The major contributors of emissions were: public hospitals (148 megatons [47%]), non-hospital purchased pharmaceuticals (56 megatons [18%]), and con-struction (46 megatons [15%]) (Wu 2019). The energy use for buildings and transport was only 16% of the emissions of medical institutions, the purchase of goods and services 84%. Among the emissions of medical institutions, pharmaceuticals have a high impact (Wu 2019). → Sustainable supply chains have a high rele-vance for GHG emissions. As raw material consumption and GHG emissions are often linked, it can be assumed, that the same is true for raw material consumption. ● To analyze or implement CE in health facilities, several sub-sectors can be considered (concerning both, production and consumption): Medical devices/equipment, pharmaceuticals, medical supplies/consumables, medical textiles, waste man-agement, energy consumption, circular construction. ● Recent international discussions concern the reduction of pharmaceutical waste: For European countries and the US, es-timates of the share of medication becoming waste range between 3% and 50%, the reduction of it can lead to environmental benefits and reduced costs (OECD 2022). ● Concerning health care waste management, currently discussed topics are: 1) HCW minimization, sustainable management, and policy-making, (2) HCW incineration and associated environ-mental impacts, (3) hazardous HCW management practices, (4) HCW handling, and occupational safety and training (Ranjbari et al. 2022).
Barriers	● No specific studies concerning barriers to a more circular health sector in China were found, but several international studies adress the topic (normally focused on specific countries or subtopics). The weighting of the challenges might be different in the Chinese context, but it can be expected that the challenges are similar. The studies considered (Mahjoob et al. 2023; Ka-zançoğlu et al. 2021; Alfina and Ratnayake 2023; MacNeill et al. 2020; Alfina et al. 2022) group challenges in categories which differ slightly but are roughly the following (with examples of identified challenges from the studies): ● Supply chain management: Challenges in taking back products (4Rs), lack of consideration for a CE supply chain, unclear vi-sion regarding CE in supply chains, lack of collaboration be-tween supply chain actors. ● Regulation/policies: lack of governmental legislation, lack of standards for existing CE, lack of incentives, regulatory struc-tures that encourage the proliferation of disposable medical de-vices. ● Financial: lack of realistic CE business models, inadequate al-location of funds, high-cost requirements for circular technol-ogies and implementations, high costs of collecting, sorting, and processing waste. ● Social: lack of consumer interest, widespread use of disposable medical products/ devices/supplies, lack of awareness about CE practices and resources, lack of the top management support and commitment about circularity, consumer perception of reused components being flawed/on infection prevention. ● Organizational/management: Complexity of circularity in healthcare systems, conflict of interest among stakeholders, insufficient product traceability, lack of a standard system for performance indicators associated with measuring CE in supply chains, unclear definition and management of waste. ● Technology: Lack of innovation in recycling plants, lack of en-vironmentally friendly disposal practices, insufficient infra-structure, maintaining the quality of products that are made from recovered materials.

Best practices	● Refurbished systems or PaaS systems for medical devices (Ellen MacArthur Foundation 2021), (GoldSeal systems; GE Healthcare 2024). ● Specific waste reduction programs for healthcare facilities (as an example, the National Health Service in England set up a strategy and intends to save £11 million per year in recurrent revenue costs and to reduce carbon emissions from waste by approximately 30%; NHS England 2023). ● HCWH (2021) present best practices to reduce plastics in the health sector (e. g. design of products using less plastics, reuse options in foodservices). ● Some local governments (e. g. Shanghai, Hunan, Zhejiang, and Shandong) introduced benchmarks for energy efficiency for hospital buildings (such as total energy/electricity consumption per floorspace or bed) (Wu 2019). ● In the Netherlands, PharmaSwap allowes certified pharmacists to sell unused/ undamaged medicine to other pharmacies before it expires (often at a reduced price). In 2020, the value of the saved packages was estimated to be EUR 184 000 for 175 packages saved (only a small part of pharmacists and 3 wholesalers were participating – if rolled out on a large scale, the savings could be much higher) (European Union 2020).
	Renewable energy installations
Trends/ Hot topics	● China has set itself ambitious targets for the expansion of re-newable energies and there is a rapid expansion of capacities (Climate Cooperation China 2023). Increased volumes of EOL wind turbines and photovoltaic modules are therefore expected in the coming years (Yang et al. 2023; Ali et al. 2023). ● The waste streams can be unevenly distributed across the country, e. g. for PV waste, Wang et al. (2022a) find that there will be a concentration in the Northern or Northwestern regions. From a temporal perspective, they find that over 80% of the total cumulative PV waste will be generated between 2040–2050. ● In 2023, Chinese authorities released guidelines to promote the recycling of decommissioned wind-power and photovoltaic equipment (The State Council of the People's Republic of China 2023a). The publication of standards for the recycling of wind turbines was reported in January 2024 (Ng 2024). ● Heat pumps are considered a relevant technology for the de-carbonization of heating in China (Su und Urban 2021; IEA 2024b; GIZ 2024). A circular design and circular business models will therefore help to decrease resource use for this technology. ● Agrivoltaic projects aim to use land more efficiently by com-bining power generation and agriculture also in China (GIZ 2023). To ensure a sustainable development, land use conflicts and local socioecological systems should be taken into con-sideration (Hu 2023).
Barriers	● Lack of technologies and capacities for cost-competitive high-quality recycling of wind turbine rotor blades (Yang et al. 2023). ● Lack of large-scale infrastructure for reuse and recycling of solar photovoltaic modules, hindered by high costs for the re-cycling of the modules and therefore low economic benefits (IEA 2022). Zhou et al. (2024) state that innovating, or im-proving the existing PV recycling process, and pursuing more low-energy and low-emission technologies could help to reduce recovery costs and increase recovery income, thus stimulating market interest. ● More bottlenecks in PV recycling: the actual concentration of PV waste recycling in small enterprises and self-employers (with no environmental protection treatment conducted and environ-mental risks following as well as losses of materials), the wide dispersion of PV modules in China, and the lack of clear policy guidance in PV panel decommissioning (which results in dif-ficult recycling access, complex cross-regional flow, uneven recycling technology, unsmooth circulation paths, and other problems) (Zhou et al. 2024).

Best practices	● First solar panel recycling pilot line set up by SDIC Yellow River Hydropower Development Co., Ltd., the largest PV enterprise in Qinghai Province. The comprehensive recovery rate is as much as 90 % with an annual processing capacity of 110,000 modules (roughly equal to 2,750 tons) (IEA 2022). ● For PV solar modules on private, municipal or commercial roof spaces: development of leasing models. Example: SolarCity (US company, acquired byTesla)

Annex IV Short-list of potential topics for SPS and short-list of policy recommendations

The recommendations for potential SPS are consolidated (short-list)[10] and are presented below:

Table 4: Proposed sectors / clusters with prioritized potential SPS topics / research questions

Sector	Research Questions
Overarch-ing / cross-sectoral	- Study to assess the potential of Circular Economy in the industry decarbonisation and climate neutrality target of China - Comparative cost benefit scenario analysis of general waste man-agement options with a focus on zero and low value waste and ana-lysing innovative financing options, e.g. CO2-credits, garbage fees, incineration tax etc. - Conceptual development and implementation of a CE label/ Recycling label in China and test the feasibility and potential of its implementa-tion in the Chinese public procurement sector as well as for accessing the EU market - Feasibility study on implementing Extended Producer Responsibility (EPR) in Waste Electrical and Electronic Equipment (WEEE), pack-aging waste and End-of-Life-Vehicles (ELV) in China on the basis of an in-depth analysis of lessons-learnt in other countries and a roadmap for implementation in China - Atlas for CE technologies in China: Analysis of best available tech-nology (BAT) for promoting CE in selected sectors and their availa-bility in the Chinese market
Plastics	- Analyze the contribution of the plastic industry (incl. packaging) to GHG emissions/ carbon budget in China and assess the potentials for reductions - Study to analyze the ongoing debate, policy and market potential and environmental and economic impacts of chemical recycling / gasifi-cation and pyrolysis in China - Research on substances of concern and exposition risks in 10 most relevant plastic products traded in e-commerce in China - Feasibility of reusable packaging in food delivery and e-commerce - Feasibility of establishing mandatory circular requirements for e-commerce platforms
Batteries	- Mapping the value chain of EV-battery recycling in China and ana-lyzeanalyze the material and economic flows as well as costs and benefits of EV battery recycling in the value chain, - Describing the techniques of collection, separation and recycling that are present in CN and develop mechanisms to improve the collection and recycling of EV batteries in China, e.g., derive feasible collection and recycling rates and develop standards for pre-treatment / ensuring high quality (include light means of transport)

[10] Initially, a comprehensive long-list of more than 40 potential topics for SPS was presented by the study team (see Annex VI). The consolidated short-list of recommendations for a potential SPS on circular economy was derived on the basis of the preferences shown by experts consulted within the scope of this study. Additionally, Oeko-Institute has initiated an online consultation of international and Chinese experts, elected by the CCICED. In this consultation, experts' opinion was sought to assess and rank the consolidated (short-list) of recom-mended SPS topics. Find the results of the consultation in Annex V.

Sector	Research Questions
Renewable energy installa-tions	- Analyze the origin, demands and environmental impacts of raw ma-terials used in renewable energy installation in China - Analyze the potential of recycling of renewable energy technologies (e.g. wind turbines, PV modules, batteries) in China - Policy instruments for improved collection and recycling of raw ma-terials from the renewable energy technologies
Textiles	- Map the technologies for textile recycling and analyze the market and material flows of waste textiles, economic operators, environmental and economic potential of implementation of fibre-to-fibre recycling in China - Study the impacts of EU textiles regulation on the fashion and textiles industry in CN and provide knowledge transfer on the EU Ecodesign for Sustainable Products Regulation.

Table 5: Proposed policy recommendations

Recommendation	Short title
Link CE to the industry decarbonization and climate neutrality targets of China	Link CE and decar-bonization
Continue setting numerical targets and indicators including a resource productivity target to enable responsible consumption of raw materials in China	Reduce consumption of raw materials
Mainstream the implementation of waste hierarchy principles (going beyond recycling, material recovery & waste management)	Mainstream waste hierarchy
Clearly define a hierarchy of different recycling options based on their environmental impact, currently available & future technology options	Hierarchy of recycling options
Define waste reduction targets in selected sectors as well as sector and material-specific recycling and recycled-content targets	Waste reduction targets
Develop an Ecodesign legislation for setting minimum mandatory (circular) standards for environmentally relevant products (similar to the EU ESPR)	Ecodesign legislation
Implement Extended Producer Responsibility (EPR) in selected sectors (e.g. batteries, textiles, EEE)	Implementation of EPR
Mainstream mandatory circular procurement at all levels of the government	Mandatory circular procurement
Set fiscal and economic incentives for private sector investments in circular businesses and supporting small and medium-scale enterprises (SMEs)	Incentives for SMEs
Promotion of research and development on circular technolo-gies and approaches for upscaling them	R&D on circular technologies
Increase transparency in the supply chain and implement awareness raising programmes on circular lifestyles (e.g. in e-commerce platforms, in schools and universities in major Chinese cities etc.) using digital technologies and artificial intelligence	Transparency in supply chain

[11] used in Annex V Summary of questionnaire-based expert consultation

Annex V Summary of questionnaire-based expert consultation

Table 6: Answers of experts consulted in relation to the potential SPS topics

Ranking	Potential SPS topic	Class	Relevance	Ambition of existing policy	Degree of implementation of existing policy	Publicly available information
1	CE in in-dustry de-carboniza-tion	High	8	4	1	1
		Moderate	0	3	4	3
		Low	0	1	3	3
		I don't know	0	0	0	1
2	EPR in WEEE, packaging and ELV	High	8	2	0	1
		Moderate	0	5	5	3
		Low	0	0	2	2
		I don't know	0	1	1	2
3	Textile recycling and material flows	High	7	1	1	1
		Moderate	0	5	3	2
		Low	1	2	2	2
		I don't know	0	0	2	3
4	Contribu-tion of plastics to GHG	High	6	3	1	2
		Moderate	2	3	4	3
		Low	0	1	2	2
		I don't know	0	1	1	1
5	EV-battery recycling value chain	High	6	4	1	0
		Moderate	1	3	3	3
		Low	0	0	1	2
		I don't know	1	1	3	3
6	Materials in REN installation	High	6	3	1	0
		Moderate	1	3	3	5
		Low	1	1	3	2
		I don't know	0	1	1	1
7	Recycling of REN technologies	High	6	2	0	0
		Moderate	1	3	2	4
		Low	1	2	4	2
		I don't know	0	1	2	2

Ranking	Potential SPS topic	Class	Relevance	Ambition of existing policy	Degree of implementation of existing policy	Publicly available information
8	REN mate-rial collec-tion and recycling	High	6	1	0	0
		Moderate	2	3	1	3
		Low	0	2	5	3
		I don't know	0	2	2	2
9	Impact of EU textiles regulation	High	5	1	0	0
		Moderate	2	2	1	3
		Low	0	2	4	2
		I don't know	1	3	3	3
10	Develop-ment of CE label	High	5	1	0	0
		Moderate	2	2	1	4
		Low	1	4	6	2
		I don't know	0	1	1	2
11	Cost benefit of waste manage-ment	High	4	1	0	1
		Moderate	4	5	2	4
		Low	0	1	5	1
		I don't know	0	1	1	2
12	Circular require-ments for e-commerce	High	4	0	0	0
		Moderate	2	3	3	2
		Low	1	4	4	4
		I don't know	1	1	1	2
13	Improve recycling of EV batteries	High	4	2	0	0
		Moderate	2	3	2	0
		Low	0	0	3	4
		I don't know	2	3	3	4
14	Atlas for CE technolo-gies	High	3	4	0	1
		Moderate	4	2	4	4
		Low	1	1	3	2
		I don't know	0	1	1	1

Ranking	Potential SPS topic	Class	Relevance	Ambition of existing policy	Degree of implementation of existing policy	Publicly available information
15	SoC in plastic products	High	3	1	1	2
		Moderate	1	2	0	0
		Low	2	1	3	2
		I don't know	1	3	3	3
16	Reusable packaging	High	2	1	0	1
		Moderate	3	2	3	2
		Low	2	3	3	2
		I don't know	1	2	2	3
17	Potential of chemical recycling	High	2	1	0	0
		Moderate	3	4	4	2
		Low	0	0	1	2
		I don't know	3	3	3	4

Table 7: Answers of experts consulted in relation to the policy recommendations

Ranking	Recommendation	Class	Relevance	Ambition of existing policy	Degree of implementation of existing policy in this field	Complexity of implementation of the recommendation
1	Link CE and decarbonization	High	6	1	1	3
		Moderate	0	5	2	2
		Low	0	0	2	1
		I don't know	0	0	1	0
2	Ecodesign legis-lation	High	6	1	1	4
		Moderate	0	4	3	2
		Low	0	1	2	0
		I don't know	0	0	0	0
3	Implementation of EPR	High	6	2	1	5
		Moderate	0	3	4	1
		Low	0	1	1	0
		I don't know	0	0	0	0
4	Waste reduction targets	High	5	2	1	2
		Moderate	1	3	3	4
		Low	0	1	2	0
		I don't know	0	0	0	0
5	Reduce con-sumption of raw materials	High	5	1	1	5
		Moderate	1	3	1	1
		Low	0	2	3	0
		I don't know	0	0	1	0
6	Mandatory cir-cular procure-ment	High	5	0	0	1
		Moderate	1	4	2	4
		Low	0	1	3	1
		I don't know	0	1	1	0
7	R&D on circular technologies	High	5	3	2	2
		Moderate	1	3	4	3
		Low	0	0	0	1
		I don't know	0	0	0	0

Ranking	Recommendation	Class	Relevance	Ambition of existing policy	Degree of implementation of existing policy in this field	Complexity of implementation of the recommendation
8	Incentives for SMEs	High	4	2	1	1
		Moderate	2	2	2	5
		Low	0	2	2	0
		I don't know	0	0	1	0
9	Transparency in supply chain	High	4	1	2	3
		Moderate	2	4	3	3
		Low	0	1	1	0
		I don't know	0	0	0	0
10	Mainstream waste hierarchy	High	3	1	0	3
		Moderate	3	4	3	3
		Low	0	1	2	0
		I don't know	0	0	1	0
11	Hierarchy of recycling options	High	3	1	1	2
		Moderate	3	3	1	4
		Low	0	1	3	0
		I don't know	0	1	1	0

Annex VI Longlist of potential SPS

Proposals for prioritization are highlighted in yellow boxes.

Table 8: Longlist of potential SPS

Sector	Research Questions
Over-arching / multiple sec-tors	**Proposal for prioritization:** ● Study to assess the potential of Circular Economy in the industry decarbonisation and climate neutrality target of China ● Comparative cost benefit scenario analysis of general waste man-agement options with a focus on zero and low value waste and ana-lysing innovative financing options, e.g. CO_2-credits, garbage fees, incineration tax etc. ● Conceptual development and implementation of a CE label/ Recycling label in China and test the feasibility and potential of its implementa-tion in the Chinese public procurement sector as well as for accessing the EU market ● Feasibility study on implementing Extended Producer Responsibility (EPR) in Waste Electrical and Electronic Equipment (WEEE), pack-aging waste and End-of-Life-Vehicles (ELV) in China on the basis of an in-depth analysis of lessons-learnt in other countries and a roadmap for implementation in China ● Atlas for CE technologies in China: Analysis of BAT for promoting CE in selected sectors and their availability in the Chinese market
	Modelling Studies: ● Study to assess the potential of Circular Economy in the industry decarbonisation and climate neutrality target of China ● Ecological and economic modelling of implementing circular economy measures in selected sectors in China (e.g. plastics, batteries, food & agriculture, construction, metals) **Technology-focus:** ● Atlas for CE technologies in China: Analysis of BAT for promoting CE in selected sectors and their availability in the Chinese market ● Comparative scenario analysis of general waste management options with a focus on zero and low value waste ● Analyze the co-benefits of the circular economy and strategic metals ● Enabler and voluntary policies ● Develop a circularity metrics for plastics and batteries and pilot the implementation in the private sector in China ● Study to develop a classification of the quality of secondary materials in China and barrier analysis of the uptake of 2nd raw materials, e.g. legislative and market barriers ● Conceptual development and implementation of a CE label/ Recycling label in China for plastics and textiles and test the feasibility and po-tential of its implementation in the Chinese public procurement sector as well as for accessing the EU market (develop a grade-based system) ● Study amendments and / or extensions towards circular procurement in the public procurement guidelines and catalogue of China ● Instruments of CE financing and investments in China: Status quo and potentials ● Analyze the potential and benefits of digitalization and AI for im-plementing CE ● Analyze the important materials, products and sectors for international trade and cross-boarder material flows in the Circular Economy for China

Sector	Research Questions
Over-arching / multiple sec-tors	**Mandatory policy instruments:** ● Feasibility study on implementing EPR in WEEE, packaging waste and ELV in China on the basis of an in-depth analysis of lessons-learnt in other countries and roadmap for implementation in selected sectors in CN – based on the introduction of EPR definitions in the CE promotion law in the next revision / a small-scale approach for CN might be considered ● Recommendations for establishing an Ecodesign legislative frame-work and a governance structure for implementing minimum product standards in China
Plastics	**Proposal for prioritization:** ● Analyze the contribution of the plastic industry (incl. packaging) to GHG emissions/ carbon budget in China and assess the potentials for reductions ● Study to analyze the ongoing debate, policy and market potential and environmental and economic impacts of chemical recycling / gasifi-cation and pyrolysis in China ● Research on substances of concern and exposition risks in 10 most relevant plastic products traded in e-commerce in China ● Feasibility of reusable packaging in food delivery and e-commerce ● Feasibility of establishing mandatory circular requirements for e-commerce platforms
	LONGLIST ● Modelling / Impact Assessment ● Study to analyze the environmental and economic impacts of plastic waste recycling in China (similar to the Zero Waste Europe Study, looking into a combination of mechanical & chemical recycling as well as incineration) ● Analyze the contribution of the plastic industry to GHG emissions/ carbon budget in China and assess the potentials for reductions ● Analyze the environmental and economic impacts and/or cost benefit analysis of chemical recycling / gasification and pyrolysis in China, thereby, describing the contribution to the dual carbon targets ● Analyze the environmental impacts of substitution of single-use plastic items in China ● Ecological and socio-economic impacts of reusable packaging in the (a) food delivery systems and (b) e-commerce in China and testing the feasibility of implementation **Policies** ● Study to analyze the potential of CO2 credit schemes and other eco-nomic instruments for the promotion of plastic recycling in China ● Potential of linking climate financing with plastic recycling in China ● Feasibility of establishing recycling and recycled content targets for plastics in China ● Study to establish polymer-specific recycled content targets in China ● Develop design-for-recycling guidelines for 3-5 major packaging ap-plications for the implementation in the Chinese market (e.g. PET bottles, HDPE containers, PP cups, PE foils) and propose mechanisms for their mandatory implementation ● Feasibility of establishing mandatory requirements for e-commerce platforms **Technology, materials and standards** ● Assessment of the market potential of biobased plastics, applications, policies (including consumer information) and standards in China ● Study to analyze the ongoing debate, policy and market potential of chemical recycling / gasification and pyrolysis in China ● Research on substances of concern and exposition risks in 10 most relevant plastic products traded in e-commerce in China

Sector	Research Questions
Batteries	**Proposal for prioritization:** ● Mapping the value chain of EV-battery recycling in China and analyze the material and economic flows as well as costs and benefits of EV battery recycling in the value chain, ● Describing the techniques of collection, separation and recycling that are present in CN and develop mechanisms to improve the collection and recycling of EV batteries in China, e.g., derive feasible collection and recycling rates and develop standards for pre-treatment / ensuring high quality (include light means of transport)
Renewa-ble energy installations	**Proposal for prioritization:** ● Analyze the origin, demands and environmental impacts of raw materials used in renewable energy installation in China ● Analyze the potential of recycling of renewable energy technol-ogies (e.g. wind turbines, PV modules, batteries) in China ● Policy instruments for improved collection and recycling of raw materials from the renewable energy technologies
	LONGLIST ● Analyze the origin, demands and environmental impacts of in-crease of raw materials used in renewable energy installation in China and potential of recycling of renewable energy technologies (e.g. wind turbines, PV modules, batteries) in China ● Technological cooperation on cleaner production / green design / ecodesign and EoL management technologies ● Analyze the routes of scrap RE installations
Textiles	**Proposal for prioritization:** ● Map the technologies for textile recycling and analyze the market and material flows of waste textiles, economic operators, envi-ronmental and economic potential of implementation of fi-bre-to-fibre recycling in China ● Study the impacts of EU textiles regulation on the fashion and textiles industry in CN and provide knowledge transfer on the EU Ecodesign for Sustainable Products Regulation.
Other sectors	**LONGLIST** ● Study to analyze the potential of CO2 credit schemes and other economic instruments for the treatment of the domestic, com-mercial and industrial organic waste in China, ● Ecological and economic modelling of implementing circular economy measures in construction sector in China": Collect examples / best practice for CE measures in the building sector and assess their applicability in CN; model the contribution of CE to carbon neutrality in the building sector and address issues like cement recycling, increase of reuse of building components and recycling of building waste ● Map possibilities of implementing net-zero cement production (including gypsum) in China ● Analyze the status-quo and BAT for construction waste treatment in Germany and assess the feasibility of implementation in China ● Policies and instruments to promote metal recycling in China ● Develop a blueprint action plan for CE measures in industrial parks, e.g. prevention of food waste in canteens, prevention of packaging waste, eco-friendly materials, optimisation of waste sorting and treatment ● Bulk solid waste excl. building, construction, chemical/petroleum industry, and agriculture: Monitor progress and (quantitatively) analyze the progress of 50 cities appointed to implement measures on bulk solid waste ● Prevention and management of food & agricultural waste ● Cost-benefit analysis of e-waste and ELV recycling compared to mining of selected raw materials

Annex VII Abbreviations, list of figures and tables

Abbreviations

Abbreviation	Meaning
AI	Artificial Intelligence
BAT	Best Available Technology
CDW	Construction and Demolition Waste
CE	Circular Economy
CEPL	Circular Economy Promotion Law
CGE	Computable Global Equilibrium Model
EIA	Environmental Impact Assessments
ELV	End-of-Life-Vehicles
EPR	Extended Producer Responsibility
EOL	End-of-Life
ESPR	Ecodesign for Sustainable Products Regulation (EU)
EV	Electric Vehicle
Exiobase	Multi-Regional Input-Output table
FYDP	Five-year Development Plan
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GTP	Global Temperature Potential
GWP	Global Warming Potential

Abbreviation	Meaning
IAM	Integrated Assessment Model
IO	Input-Output (model)
LCA	Life-Cycle Analysis
LFP	Lithium-Ferrophosphate-Accumulator
LU	Land Use
MFA	Material Flow Analysis
MIIT	Ministry of Industry and Information Technology
MRIO	Multi-Regional Input-Output (model)
NDC	Nationally Determined Contribution
NDRC	National Development and Reform Commission
PV	Photovoltaic
REN	Renewable Energy Technologies
RMC	Raw Material Consumption
SME	Small and Mid-sized Enterprise
SPS	Special Policy Study
WEEE	Waste Electrical and Electronic Equipment

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