CCICED

SPECIAL POLICY STUDY REPORT

Major Green Technology Innovation and Implementation Mechanisms

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Executive Summary

1 Significance of the Study: Green Development and Green Technology Implementation Are the Only Options for Urban Development in China

Cities are important for achieving emission reduction targets and for transforming development patterns. Their share of emissions and the total amount of emissions will both increase significantly in the future. Cities must reform the current financial and taxation system and GDP-oriented schema, using the green development concept. Cities must get rid of the development path of high input, high consumption, and high carbon emissions, thereby escaping the "lock-in effect" and fulfilling the country's commitments on the Paris Agreement.

The next decade will be a period of significant opportunity for the development of green cities and green technologies. The urban population is expected to grow by 150 million over the next 10 years; middle-income groups will be concentrated in cities, with new values and lifestyles. The huge increase in population and consumption that leads to resource wasting and emissions, however, is the driving force and opportunity for green transformation of the cities.

Green technology implementation is the main path to achieving the green transformation of cities. Many European and North American cities are aiming for "zero-carbon, zero-waste, healthy ecosystems" when building green cities that thrive. In this process, green technology is specifically used to reduce consumption, to lower emissions, and to improve the environment. The innovation and implementation of green technology enable these municipalities to foster green living and consumption patterns of citizens so as to share the benefits of green development.

2 Focal Points

2.1 Analysis of the Main Current Issues

Green development is the only alternative for Chinese cities, for which a widespread application of green technology is an inevitable requirement. However, in practice, we find that all the entities, including city governments, still lack the motivation and practical measures to develop green technologies. Therefore, we need to first recognize the issues on

the innovation, implementation, and promotion of green technology currently in China, in order to make problem-oriented policy recommendations.

2.2 Construction of the Assessment Methodology

Previously in China, the promotion of green technology had considered economic and industrial factors more than green and low-carbon targets; also, a promotion usually becomes a short-term "movement," ignoring the systemic nature of the urban development process. Particularly, massive resources are wasted when some technologies and products are hastily scaled up without any full life-cycle financial feasibility assessment. Therefore, it is crucial for successful green technology promotions that a proper method is built for conducting comprehensive, multi-dimensional assessments on every technology.

2.3 Identification of Key Areas for Comparison Between China and Other Countries

The progress of innovation and implementation of green technology not only needs systematic promotion, but also, given the identification of the present issues, demands the combination of advanced foreign and local experiences, an emphasis on public interests, and a focus on selected key areas related to technical and applicational challenges.

2.4 Development of a Technology Inventory

Regarding the Chinese and foreign outstanding technical experiences and emerging best practices, as well as the key areas identified, a list of green technologies has been screened out using a full life cycle of technology assessment, each of which is pioneering, comprehensive, innovative, and effective, as a contribution to the technological strategy in the 14th Five-Year Plan (FYP).

2.5 Multi-Level Policy Recommendations

Under the current fiscal and tax system and GDP-growth evaluation approach, city governments are still mostly concerned with economic development and continue to rely on land capital investment, rather than transferring the development model and promoting green technologies. Therefore, the innovation and implementation of green technologies cannot be separated from a profound multi-level enhancement of laws and regulations, government policies, including business responses and public participation.

3 Policy Recommendations

3.1 Green Vision and Goals

The vision of green city development: Through green technology innovation and implementation, help green producing and living become the mainstream choice of society, and help Chinese cities become green, low-carbon, recycling, equitable and inclusive, safe, healthy, and beautiful, providing a "Chinese model" for the world's sustainable development.

The overall goal of green technology development: From reducing consumption and emissions, improving the environment, and realizing green and low-carbon development, fulfill the people's desire for a better life, meanwhile fostering wide participation in the green economy and lifestyle throughout society. Through the construction of green cities and the implementation of green technology, improve the country's international competencies in green development and achieve "green prosperity."

3.2 Establish and Improve the Full Life Cycle and Full-Cost Green Technology Assessment System

Establish an assessment system for green technologies in terms of the full life-cycle cost, from comprehensive perspectives consisting of emission reduction effectiveness, economic rationality, production feasibility, and user acceptability.

Full life-cycle assessment—before, during, and after use: Green technology is not merely about its application but also about the green benefits that occur beforehand and afterward. A green technology assessment approach should take the whole life cycle (from design to disposal) of a product into account, targeting the green benefits at all stages, including design, resource extraction, production, maintenance, and decomposition.

Multi-dimensional full-cost assessment—incremental costs and benefits: In addition to the effectiveness of carbon and consumption reduction, the assessment should consider the economic benefits and financial viability, as well as the social recognition and acceptance. Hence, we propose a multi-dimensional assessment framework that reflects all of the environmental, economic, and social costs and benefits.

Assessment framework across three time stages + three core dimensions: The full-cost life-cycle green technology assessment framework covers all the stages (pre-implementation, implementation, and post-implementation) and all the dimensions of their costs and benefits (environment, economy, and society).

3.3 Key Areas of Green technology and Recommended Technology List

Pertaining to the advanced experiences from Europe and North America and based on the main problems of China's current urban development, as well as the technological and applicational challenges in all the relevant areas, we suggest water, energy, transportation, buildings, land use, and food as the key pillars of urban greening during the 14th FYP. In these prioritized sectors, we suggest promoting the implementation of 20 green products with the greatest energy-saving and carbon-reduction benefits and residents' sense of gain.

Table 1. Recommendation for green technology in six major sectors during the 14th FYP

Major Sectors	**Technical Development Director**	**Recommended Technology**
Water	Sewage Treatment and Water Recycling Economy	Sewage Treatment and Plant, Network and River Integrated Quality and Efficiency Improvement Technology
	Utilization of Reclaimed Water	Water Quality Guarantee Technology for Recycled Water System
	Utilization of Reclaimed Water and Non-Revenue Water Management	Smart Operation Technology for Recycled Water
Energy	Integrated Green Energy Grid	Microgrid Technology
	Near-Zero-Emission Cooling and Heating	Industrial Waste Heat Central Heating Technology
		Middle-deep Geothermal Heating Utilization Technology
	Energy Internet	Integrated Energy Internet Management Platform Technology
Transportation	Intelligent Transportation System	MaaS Travel Service Technology
	New Energy Vehicles and Supporting Facilities	Hydrogen-powered Vehicle Technology
		Intelligent Charging System Technology
	Transportation Demand Management and Cycling Trip	Bicycle Special Road Technology
Building	Healthy Building	Building Three-dimensional Greening Technology
	Green Building	"Steel Structure+Modular Internal Space" Technology
	Near-Zero Energy Building	Photovoltaic, BIPV, Distributed Energy Storage and DC Power Supply Technology
	Smart Operation and Maintenance of Building	Intelligent Building Cluster System Technology
Land Utilization and Planning	Green Urban Form	Technical Package for Green Urban Form
	Green, Livable, and Carbon-Neutral Block	Technical Package for Green, Livable, and Carbon-Neutral Block
Food	Food Traceability	Food Safety Information Monitoring and Tracking Technology
	Urban Agriculture	Vertical Agricultural Technology
	Smart Agriculture	Digital Food Platform Technology

3.4 Gender Perspectives and Cross-Cutting Solutions

Gender policies for green technology: Women should be provided with more opportunities for professional training and research on green technology. More jobs are to be created for women in the sector of green technology. In the production of green solutions and products, a gender-sensitive policy must be applied. Make sure that women are duly represented in the formulation and decision making regarding green policy. More women should be encouraged to take part in urban green development and governance. A survey on the demand data of women should be included in green product R&D. Also, women are encouraged to participate in the promotion and scaling up of green solutions and green products.

4IR new technologies: Select pilot cities to carry out 4IR new technology application and incubation, data collection and application, and the formation of replicable innovation models. Promote technological innovation for sustainable and inclusive economic growth through the design of new policy tools.

Circular economy: Integrate the circular economy into urban planning, with clear goals, roadmaps, and financial and tax mechanisms to guide businesses, research institutions, and active public participation. Establish a multi-party cooperation platform and networked regulatory mechanisms for government, market, and society.

Data governance: Create a platform for public and private sector data sharing. Ensure data sharing, data privacy, and data security by establishing policies and regulations for data stewardship and accountability.

4.5 Implementation Recommendations

(1) General Policy Recommendations

Overall national strategy and legal system building. Formulating a national plan for green and low-carbon development, setting overall carbon emission targets, timetables, and roadmaps for fulfilling the Paris Agreement commitments. Accelerate the promotion of a national and local legal system for green and low-carbon development and carbon emission control.

Building policies and institutional mechanisms for green and low-carbon development. Establishing a sound system of administrative, fiscal, and taxation policies and safeguards for green development. Clearly define the tasks of total carbon emission control, break it down to provincial, municipal, and county levels, and supervise its implementation. Carry out ultra-low/zero-carbon city and community demonstrations and demonstration projects in six areas of recommended technology implementation.

Establish a green financial system. Encourage social capital and private capital to participate in green development and green technology investment, and improve enterprise financing. Promote green investment principles and encourage the financial sector to abandon non-green, high-emission investments.

Give full play to the main role of enterprises. Establish green- and low-carbon-oriented policies on resource pricing, carbon trading, financial subsidies, tax constraints and incentives, and encourage enterprises to participate in green technology development. Actively invest in green technology research and development, production, and application. Promote the construction of a green low-carbon circular economy system.

Establish a public participation mechanism. Promulgate laws and regulations to ensure the participation of the public and social organizations in green, low-carbon and emissions reduction-related decision making, and clarify the public's interests, responsibilities, and powers. Mobilize the public to practice green living and consumption patterns. Fully implement a carbon emissions information disclosure system and disclose information on carbon emissions of cities and enterprises.

Promote green technology innovation and research. Establish a green technology innovation system that is market-oriented, widely engaged in by enterprises and is actively participated in by professional organizations.

Strengthen international cooperation on green technology. Establish an international alliance on green technology and innovation to build a communication platform for enterprises, policy-makers, and expert groups to jointly address urban green development issues along with climate change response issues.

(2) Specific Policy Recommendations in the Six Focus Areas

Water sector: Establish a multi-layered legal regime for recycled water; build sponge cities, sewage treatment, and a mechanism for assessing recycled water targets; set standards for wastewater reclamation discharge in specific areas; provide financial and tax support and VAT exemptions for energy efficiency and water treatment technologies; pilot model cities with plant and river networks and integrated water systems, and circular water-saving cities.

Energy sector: Place emphasis on the development of a renewable energy priority law, energy product pricing reform, and carbon tax policy; the development of integrated energy plan; and the reform of the green tax mechanism.

Transportation sector: Establish a regulatory system for hydrogen energy management and safety and a management system for battery recycling; strengthen the management of the

production, selling, and use of electric bicycles; develop technical standards for MaaS travel services; build demonstration projects for bicycle lanes; build pilot projects on zero traffic-emission zones and a congestion charge.

Building sector: Implement the dual control of energy total consumption and energy intensity; incorporate the green building performance target, total energy consumption, and energy intensity into urban planning standards; include the purchase and occupation (including rental) of green buildings in the special tax deduction benefits, and encourage enterprises to develop their own green buildings. Construct pilot demonstration cities/urban areas of near-zero energy buildings.

Land use and planning sector: Promote legislation on the development and protection of national land and space; carry out supervision, inspection, and supervision of high-rise residential projects; establish evaluation and inspection systems for low-carbon pilot city and pilot community planning, industrial land performance assessment system, and dynamic management mechanism; develop standards and norms related to mixed land use.

Food sector: Improve legal safeguards for food safety and traceability systems; promote the management of the entire food production process from source to consumer; establish a tracking and tracing system for the whole industry chain of agricultural product development; formulate technical guidelines on vertical agriculture.

(3) Policy Recommendations Based on International Best Practices

Create guidance for city- and building-level design. Guide for green and low-carbon development and transit-oriented development in Chinese cities; set and promote a standard for green buildings based on the best international practices.

Invest in new urban infrastructure. Continue with the New Infrastructure plan to help stimulate the economy post-COVID-19. Add three key urban green technologies to the list of new infrastructure investments: building-integrated photovoltaic (BIPV), water treatment technology, and energy storage, with ambitious targets for each. In order to build an integrated green energy grid (IGEG), double annual investment in wind, solar, and energy storage.

Continue to drive the adoption of electric vehicles. Strengthen the construction of electric vehicle infrastructure; focus on promoting the electrification of high-mileage commercial vehicles, promote shared vehicles, and implement a transport demand management.

Promote digital innovation along the food value chain. Enable robust innovation ecosystems, apply digital innovation to the whole food value chain, improve traceability in food supply chains, produce and adopt healthier, more nutritious and sustainable diets, and promote urban indoor farming.

Build carbon-neutral communities. Make clear targets and a shared roadmap for carbon-neutral, circular communities, mobilize government departments, the private sector and all stakeholders to participate in the construction of carbon-neutral and circular communities.

Delivery mechanisms. Three strategies that will help to achieve a green transition in Chinese cities include: pilot cities and policy sandboxes, a cross-border alliance on green technology, and engagement with the public.

Contents

Preface

Ecological civilization. The Chinese government has established ecological civilization as a basic strategy guiding China's future development. The principles of "green development for a beautiful China" and "people-centered development" constitute the core values and visions for China in the new era of civilized development with a sound ecosystem.

The fundamental purpose of ecological civilization is to ensure ecological safety through lower and more efficient use of natural resources, exerting the service function of ecological capital. With reduced emission of carbon and other pollutants, extensive and unsustainable growth mode should be changed to an ecologically friendly development path. Through green development, green prosperity can be realized and people can share benefits of green development, reaching the harmonious coexistence of humanity and nature.

Respond to climate change. By 2015, three international legal instruments addressing climate change—namely the United Nations Framework Convention on Climate Change (UNFCCC), Kyoto Protocol, and the Paris Agreement—had set the framework for global climate governance and low-carbon green development. The Paris Agreement determined "to keep the increase in global average temperature to well below 2 ℃ above pre-industrial levels," and stipulated the "common but differentiated responsibilities" among countries. As a signatory, China has made a commitment to reach a peak of carbon emissions by 2030 and to reduce carbon emission intensity by 60%–65% compared with 2005 so as to undertake its responsibilities as a major country in dealing with climate change.

Green development. Western countries, especially the EU countries, pay close attention to green development. According to the European Green Deal issued in 2019, by 2050, Europe will become the world's first "carbon-neutral" area. The newly elected EU institutions came up with the concept of "Green New Deal." For the first time, China's 13th FYP clearly proposed the green development goal of "overall improvement of ecological environment" by promoting the implementation of resource conservation and intensive utilization, increasing comprehensive environmental governance, strengthening ecological protection and restoration, actively responding to global climate change, and developing green and environmentally friendly industries—it also identified 27 green development projects in four categories. Green development has become one of the five concepts and a strategic and programmatic idea guiding the development of China in the new era.

"Green city." Many European and North American cities have put forward goals and action plans of building green cities and carbon-neutral communities, and published important documents to promote urban green development, such as the *Aalborg Charter*, *Aalborg Commitment*, *Leipzig Charter* and *Freiburg Charter*. In its Vancouver: 2020 action plan of the

greenest city, Vancouver has proposed the goal of "zero-carbon, zero-waste, and sound ecosystem" and a series of target areas, including energy, water and transportation, to build a green city of prosperity and development.

Chinese cities are areas with concentrated population and economy and intensive resource consumption and emission; green development becomes the only choice for Chinese cities. In recent years, the Chinese government and relevant departments have promoted development action plans such as "sponge city," "ecological city," "green new area," "low-carbon city," "low-carbon community," "ecological restoration," "urban repair," and "waste-free city," carried out many pilot and demonstration projects, and explored the ways of urban green development.

Green technology. The term "green technology" refers to technologies that can reduce consumption, decrease emission, and improve ecological environment, including technologies applied in exploitation, production, manufacturing, construction, planning, design, utilization, maintenance, and management. A wide application of green technology is necessary for cities' development. China's international commitments to addressing climate change and its emission reduction policies, as well as its increasingly stringent environmental governance policy requirements are driving the application of green technology in urban areas on a larger scale.

The 14th FYP period is a critical one for China's urbanization and urban development transformation. Boosting new urbanization with the development of green and low-carbon technology and promoting green development and application of green technology during new urbanization are core tasks for China to cope with climate change, as well as to stimulate the green economy after COVID-19.

Popularization and application of green technology. In 2018, the Chinese government proposed that we should promote green development, accelerate the building of legal institutions and policy guidance for green production and consumption, establish and improve the economic system of green, low-carbon, and circular development. It also proposed that we build a market-oriented green technology innovation system to develop green finance. According to the *Guidance on Building a Market-Oriented Green Technology Innovation System* issued in 2019, the market-oriented green technology innovation system should be basically completed by 2022.

Green technology has good positive externalities, good social and environmental benefits; green technology has a certain public welfare nature, and has huge potential market demand, and should be supported by society and government. Under the traditional resource utilization model and market pricing mechanism, green technology often lacks price competitiveness. We should adopt a resource pricing mechanism and ask producers or users to cover all the

costs (including external costs) so as to realize fair competition between green and non-green technologies and products. Or we can give support to green technologies and products through proper fiscal subsidies. Green technology should continue to innovate so as to lower costs and increase market competitiveness.

Green technology is an emerging high-tech and innovative sector attracting a lot of attention. We should actively encourage and support its development and build a credible information distribution system and full life-cycle assessment procedure to avoid falling into the trap of blind promotion.

Popularization of green technology should involve wide participation from the government, higher learning institutions, professional organizations, enterprises, social entities, and the public. The government should establish a complete system of laws, regulations and policies to encourage universities and professional institutions to participate in the research and development of green technology; encourage enterprises to actively research and develop, produce, and apply green technology, while paying more attention to the differentiated demands and consumption abilities of different gender, age, and capability groups; advocate green lifestyle and green consumption concepts to the society and the public; and form a good environment for the whole society to participate in green development and apply green technology.

The research emphasis of green technology SPS. The SPS on *Major green technology innovation and its implementation mechanism*, issued by China Council for International Cooperation on Environment and Development (CCICED) is committed to the research of green development, promotion and application of green technology, evaluation methods, laws, and policies in urban areas. Through research, it recommends 10 to 20 scalable green innovation technologies, conducts a comprehensive assessment from the perspective of the full life cycle to provide technical support for the green development policy of the 14th FYP, and at the same time, puts forward suggestions on the policy guarantee system of green technology promotion.

1 OPPORTUNITIES, VISIONS, AND GOALS

1.1 Characteristics, Problems and Opportunities of Urbanization and Urban Development

Urbanization and urban population growth have created an increasing amount of pressure and opportunities for urban transformation. With the urban population

accounting for 60% of the total population in 2019, China has transformed from a traditional agricultural society to an urban society, and it will see a further increase in its urban population by about 150 million over the next 10 years. Among the floating population who are already working and living in urban areas but not officially registered as urban residents, about 100 to 150 million will settle down in cities and counties to enjoy family reunion. The population increase and the need to settle down will generate huge new demand and resource consumption, and also provide the cities with opportunity to change the development mode and optimize resource allocation.

Cities are where most resources are consumed and most carbon is emitted, but also the core places for green and low-carbon development. Industry, construction, and transportation are the three major resource consumers and are mainly concentrated in cities. Cities are where most emissions are generated and also the core places for achieving green and low-carbon development throughout society. Under the influence of GDP-oriented policies and existing financing and taxation policies, a model featured with extensive use of resources and blind expansion of land was formed in Chinese urban areas. Fragmented urban layout, inefficient use of land, dislocation of infrastructure and public services, and inefficient transportation operations have led to a perpetuating high level of carbon footprint and created a "lock-in effect."

Increases in expansion of consumption are putting greater pressure on supply, and also driving a transformation of lifestyle and consumption. Rising per capita income has witnessed a continuous expansion of China's middle-income group which now accounts for about 30% of the total population. The driving force for social development has shifted from meeting the needs for food and clothing to pursuing a better life. The values and lifestyles of the middle class are taking shape. On the one hand, increased consumption power of urban residents is leading to more resource consumption for material and cultural needs and more emissions. On the other hand, the emerging middle class and well-educated young people are more open to green and low-carbon value and rational lifestyles. It is a good opportunity to advocate low-carbon lifestyles and consumption, and to promote green development and green technology in cities.

Policy change from focusing on seeking additional resources to focusing on utilizing existing resources has created new space for applying green technologies. Chinese cities have accumulated a large amount of existing assets, including inefficiently used or idle land, infrastructure, industrial, and civil buildings. China is asking its cities to shift the focus of their development from increasing additional assets to utilizing existing assets efficiently. It proposes new ways and scenarios of promoting green technologies, including but not limited to multifunctional and hybrid land development, low-carbon reconstruction and multiple use of buildings, organic renewal of cities, development of low-carbon communities, green

slow-moving transportation, distributed energy supply, and the principles of the circular economy.

Huge differences between cities require different green development strategies and green technology supplies. China's natural resource and population are extremely unevenly distributed, there is a gap of natural condition and development level among the eastern coastal, central and western regions, and the northern and southern regions. There are also big differences in development levels, needs, and capabilities between large cities, mid-size cities, and small towns. Different areas respond differently to natural disasters caused by extreme weather, rising sea levels caused by climate change, etc. Urban green development should have a "common but different" strategy and path; green technology research and promotion should be highly targeted and adaptable. It also provides various driving forces for the development and innovation of green technology.

1.2 Vision and Criteria for Urban Green Development

The vision of urban green development is to make green industrial production and everyday life the mainstream choice of society through green technology innovation, promotion, and application, and to **build beautiful cities that are green and prosperous, low-carbon and intensive, recycling and reusing, fair and inclusive, safe and healthy to set a "Chinese example" for global sustainable development.**

Green and prosperous cities: We should build a high-quality green economy, promote the development of low-carbon industries, circular economy, and green consumption, and make green development the core competency of cities and the core value of society.

Low-carbon intensive cities: We should optimize urban layout, advocate mixed land use, encourage green transportation, promote green buildings, green infrastructure and low-carbon communities, and completely abandon the urban development model of high consumption and high emission.

Recyclable and reusing cities: Cities should aim to use all resources to their maximum efficiency, including underused city and building space, transportation that shares resources such as bikes and cars. Waste can be recycled or reused. Resource recycling replaces the expanding and incremental development mode.

Fair and inclusive cities: We should provide residents with fair access to quality life and ecological capital services regardless of gender, status, age and identity (*hukou*) status; provide residents with equal access to and participation in green development.

Safe and healthy cities: With a continued focus on ecological conservation, we should mitigate conflicts between cities and nature, protect valuable natural resources and ecological capital for contemporary and future generations of residents, so as to create a

healthy and livable environment, and improve the health and well-being of urban residents.

In order to achieve the vision, urbanization and urban development should follow:

Criterion 1: Urban development serves to meet people's need for a good life and to achieve harmony between humanity and nature, not just for economic growth;

Criterion 2: We must pursue prosperity, but just as importantly we must make direct contributions to the reduction of global resource consumption and carbon emissions while adopting climate-resilient development strategies to cope with changes;

Criterion 3: Urban green development not only requires the government to make great efforts but also should give full play to market entities and encourage broad participation by enterprises and the public;

Criterion 4: Urban green development should be oriented toward fairness and justice, and should not harm the welfare of women, the elderly, children, and mobile residents or deprive vulnerable groups of their development rights;

Criterion 5: Urban green development should establish differentiated strategies and paths to adapt to all natural conditions, different stages of development, and development needs and capabilities of cities and regions at different levels;

Criterion 6: Urban green development should be oriented toward effectiveness and applicability, and requires multi-dimension life-cycle assessments of green technologies to avoid following suit and steer away from "new technology pitfalls."

1.3 Goals and Approach for Urban Green Development

General goal: Based on the concept of "ecological civilization" and new development outlook, we aim to realize modernization in a way that human and nature live in harmony, with such spatial layout and economic activity distribution pattern that are conducive to conserving resources and protecting the environment. "Green and low-carbon" will become the theme of both work and life, and the idea of green development will be implemented in all aspects and processes of urban economy, as well as social development and environmental evolution. Ultimately, green and low-carbon development will become the norm, and the vision of "beautiful China" will be materialized.

2020–2025 (The 14th FYP in China): Priority is given to the green development and green technology application in key sectors including water, energy, architecture, urban planning, transport, food, etc. to overcome the lock-in effect. Starting with pilot programs, policy measures and framework of standards should be improved; meanwhile, a green finance market that harmonizes with its international counterparts should be put in place. Promotion

of green solutions and products among industry and consumers will be boosted through the constant improvement in measures such as emission permitting, supervision, reporting, monitoring, auditing, and standards formulation. During this stage, the total emissions of greenhouse gases will be significantly cut and the eco-environment quality notably improved.

2025–2030: Put in place a world-leading technical system for green development; popularize the concept of urban green development and the application of green technology. Sophisticated legal, institutional, and policy frameworks should be established so that the way of production and life is directed to shift toward a greener style. China should aim for the early-attainment and over-achievement of its national commitments under "2030 UN Sustainable Development Goals" and the Paris Agreement.

Post-2030: With reference to the national development objectives and the goals of 2℃ and 1.5℃ in the Paris Agreement, drawing lessons from the EU's zero-emission goals and roadmap for 2050, green technology should be applied in cities across China. An economic system featuring green development will be established. Resource conservation, circular use of materials, and in-depth emission cutting should become the universal themes. Relevant legal instruments and policy measures should be institutionalized to guide and support green production and consumption. By 2050, green development will be the paradigm of choice for the whole of China, where according to the plan, the vision of "beautiful China" will be realized. With these achievements, China will make its outstanding contributions to the global 1.5℃ goal.

In accordance with the general goals and stage goals stated above, the objectives for urban green development in six key sectors are listed in Table 2.

Table 2. Goals for each stage in six key sectors of developing green technology

	2025	**2030**	**Post-2030**
Water management	Build a well functioning network for sewage collection and treatment.	All urban sewage is collectively treated; more water is recycled, to a higher technical standard.	Water environment quality is significantly improved; sustainable use of water is on a par with the standards in major developed countries.
Energy	Put in place a green, intelligent and networked energy system. Incremental demand is primarily met by clean energy. Realize the equal price of renewable energy and coal.	Renewable energy and nuclear energy enjoy an increased proportion in the energy mix, while fossil fuels are decreasing significantly; clean energy becomes the mainstream.	Energy efficiency reaches a level that represents world-leading standards; energy consumption peaks; fossil fuel is completely replaced by new and renewable energy.
Transport and mobility	Formulate frameworks for green solutions, standards, and application support measures; constantly	Reach a leading international standard for smart and low-carbon technology; a sophisticated system for green solutions, standards, and	A complete system of green, ultra-low-carbon, intelligent transport is put in place.

	optimize the energy structure and make tangible achievements in emission cutting in the transport sector. Encourage electric car and motor vehicle to improve ridership.	application support measures is established. All public transport and delivery vehicles are electrified; significant emission cutting is achieved.	
Architecture	Green building standards are applied on all newly built civil architectures; buildings sport cleaner and greener energy systems.	All newly built civil architectures feature ultra-low energy consumption level or even better.	All newly built civil architectures are zero-energy consumption. All existing buildings are upgraded into energy-efficient buildings.
Land use and planning	Green development concept is implemented in all processes of planning and construction management; the pilot programs of green cities and green communities are scaled up.	Prioritize the "green transformation" of settlement environment in key urbanization areas. A number of world-class green cities and green communities take shape.	The overall living environment in urban areas and neighbourhoods features the quality of green, low-carbon, livable, and prosperous. "Ecological civilization" is achieved.
Food	Address the issue of food safety; cut emissions from food production.	Improve the health of the food chain; advocate greener diet structure.	Build a green, low-carbon, nutritional, and fair system of food supply and demand.

To achieve the goals above, a green technical system should take into account the economic, social, and cultural features of cities. In order to cover all relevant processes in life, work, and leisure of urban citizens, the system should account for each link of the value chain: "resource conservation and utilization; production and building; consumption and use; decomposition and recycling." The green technical system would facilitate the realization of green development goals by addressing the salient issues of "not green enough" and high emissions in urban development in China. For a green technical system to be established, technologies on the following fronts should be developed and promoted:

Conservation and reduction in the use of shared natural resources. Ecological red lines must be strictly observed, and the natural landscape should be left undisturbed as much as possible. The energy-intensive, high-emission urban development approach will be abolished; and shared natural resources should be used in a rational and frugal manner and be fairly distributed.

"Circular" production and building. In the process of production and building, resources should be used in such a way that maximizes efficiency and minimizes consumption and emissions, while producing high-quality, high value-added green products.

Responsible consumption and use. Cultivate the awareness of responsible consumption and the good behaviour of careful use and protection of materials, so as to reduce the life-cycle

consumption of resources, carbon emission, and environmental pollution, while improving the standard of living and net well-being benefits for urban citizens.

Safe decomposition of waste and resource regeneration. Taking zero-carbon emission as the ultimate goal, high-standard treatment and recycling of solid waste, waste water, and exhaust gases will be rolled out. Consequently, the vision of "zero-waste city" and "zero-pollution environment" will be realized.

2 EXISTING POLICIES AND PROBLEMS

2.1 Existing Policies for Urban Green Development

After the 1992 United Nations Conference on Environment and Development, as a party to the Convention, China issued the "China Agenda 21—China's 21st Century White Paper on Population, Environment and Development." Since then, it has continued to advance through laws, policies, planning, and standards, actively building and improving laws and policy systems related to sustainable development, energy conservation and emission reduction, green development and low-carbon development.

At the macro level, in recent years, the state has issued a number of important policy documents on ecological civilization construction, sustainable development, new urbanization construction, urban planning and construction management, etc., to promote the sustainable development of ecological civilization in the field of urbanization and urban development. The policy document emphasizes that urban construction must be "people-oriented," taking into account the multi-dimensional development goals of economy, society, resources, environment, and culture, and attaching importance to the role of reform and innovation and technological progress. These policy documents show that the Chinese government attaches great importance to urban green development and also proposes goals and requirements for urban green development.

Table 3. Selected macro-level policy documents for urban green development

Time	Title of document	Key points
2014.3	"National New Urbanization Planning (2014-2020)"	Enhance urban sustainability; build livable, dynamic, and modern cities with unique characteristics
2015.4	"Opinions on Accelerating the Development of Ecological Civilization by the Central Committee of CPC and the State Council"	Building a society featuring resource conservation and environmental friendliness; mainstream the values of "ecological civilization"
2015.12	"Gazette for the 2015 City Work Conference of CPC Central Committee and the State Council"	Sustainable urban development and livability
2016.2	"Opinions on Driving New Urbanization to Greater Depths by the State Council"	New urbanization, sustainable and healthy economic growth
2016.2	"Opinions on Improving the	Manage orderly construction, moderate land

	Management of Urban Planning and Construction"	development, and efficient operation of cities; build livable and dynamic urban environment with unique characteristics
2016.3	"Outline for the Thirteenth Five Year Plan"	"Urbanize the people"; optimize urban spatial layout and morphology; build harmonious, livable cities; achieve coordinated development of urban and rural areas
2016.9	"China's National Plan on Implementation of the 2030 Agenda for Sustainable Development"	Build inclusive, safe, disaster-resilient, and sustainable cities and human settlements
2016.12	"China's National Plan on Implementation of the 2030 Agenda for Sustainable Development"	Build innovation demonstration zones for National Sustainable Development Agenda
2017.4	"Chapter on Urbanization and Technology Innovation for Urban Development" of the Thirteenth FYP	Technological innovation system in urban development
2017.10	Report of the CPC 19th National Congress	New type industrialization, informatisation, urbanization, and modernization of agriculture; shared responsibility and benefits of growth; harmonious coexistence of humans and nature
2018.8	"Opinions on Developing Safe Cities by the Central Committee of CPC and the State Council"	Urban security, disaster prevention, and public security

In response to climate change, promoting energy conservation, emission reduction, and low-carbon development, the Energy Conservation Law was promulgated in 1998, and the Renewable Energy Law was promulgated in 2006, gradually forming three types of systemic policy tools: policies to address climate change, climate change assessment report, energy-saving and emission reduction work plan. The country has successively issued the "China National Plan to Address Climate Change," "The 13th Five-Year Comprehensive Work Plan on Energy Conservation and Emission Reduction," "The Medium- and Long-Term Development Program for Energy," "Administrative Measures for the Operation of the Clean Development Mechanism Project," and "Green Travel Action Plan" along with many other policy documents. In terms of standard specifications and technical regulations, national or local technical regulations have been formulated for cities, communities, buildings and other fields, including "Green Building Evaluation Standards," "Guidelines for Corporate Greenhouse Gas Accounting and Reporting," and "Low-Carbon Community Pilot" Construction Guide, etc. However, compared with the EU's green and low-carbon laws, policy financing, and market standards that complement each other, China's urban green development and green technology promotion and protection systems are still not perfect.

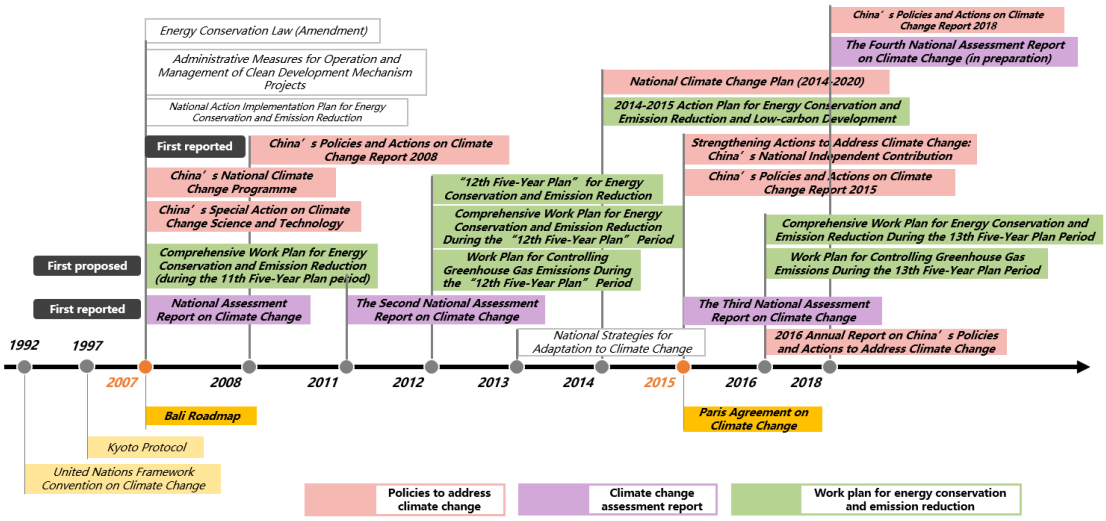

Figure 1. The development course of low-carbon development policy in China

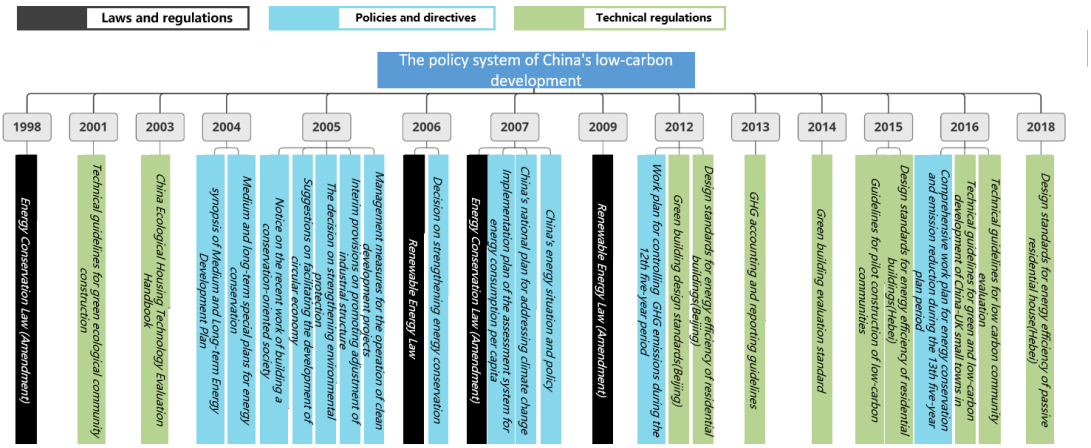

Figure 2. The major law and policy of China's energy-saving and low-carbon development

2.2 Analysis of Existing Problems of Urban Green Development

Despite the consensus on green development among cities, some problems remain prominent in its implementation.

Legislation lags behind practice. When it comes to green development, China lacks a systematic legislation framework. Existing laws and regulations are primarily single-purpose for issues such as environmental protection, pollution prevention and treatment, or energy use, etc., with stress on the limits. There are no laws to direct comprehensive green development and carbon reduction. Green development is more driven by government policy rather than continuously bolstered by laws and regulations.

Goals and indicators for emission reductions are absent. The currently binding targets for

emissions reductions are too conservative and fail to match the commitments China made at the Paris Climate Conference and the global trend of going green. The lack of systematic objectives has made it difficult to allocate tasks and responsibilities to local governments.

Coordination between departments is weak. Green development is a systematic cause that requires the coordination of multiple departments. However, because the division of responsibilities is not clearly defined, and the coordination mechanism is weak, no one embraces the responsibility. Take the shared bike service as an example: it involves over 10 departments and various layers of the government. Some departments welcome the service while some others prefer putting restraints. Such inconsistency among different decision-makers finally gave rise to a large-scale "quick flood and ebb" phenomenon.

The green financing system is still next to non-existent. China has seen a significant increase in green and environmentally themed investment year-on-year over the last couple of years. However, the source of green funding is rather limited: companies relied almost solely on themselves to raise the capital needed since there are few other options available. Green finance is still in its infancy in China. Problems such as the inconsistency in green accreditation and the confusion in claiming green finance collateral have kept financial institutions away from funding green projects. Besides, there are no expressly stated principles and guidance for green investment in the financial sector.

Businesses are not keen on the idea, and thus the green value chain has not taken shape. At present, the popular way of encouraging businesses to participate in green technology innovation and application is through fiscal subsidy. But candidate technologies were often not evaluated in a scientific manner; consequently, many projects that are truly "green" are not properly subsidized. Also, China doesn't have a mature carbon trading market that can generate enough profit as reward. The poor liquidity and low pricing of carbon in the current market have held companies back from taking part. Besides, China doesn't have the policy tools to encourage and facilitate knowledge transfer, commercialization, consumption, and application of green technology.

The support system for green technology innovation is not well developed. Technological innovation is the key underpinning pillar for green development. Unfortunately, on that front, the current situation in China is that while universities are enthusiastic about R&D, businesses take quite the opposite attitude when it comes to green technology and products. International collaboration is another weak point. The status quo makes the innovation community slow in picking up market demands and incapable of effectively translating R&D results into solutions and products that address business and household needs.

Public awareness and participation are low. The values of green and low-carbon have not yet taken root in society. The reasons for this include: the general public don't know where

and how to take part in urban green development; there is a lack of a trustworthy platform to disclose green performance and emissions data; there is not yet a professional and inviting social education system; etc. On the other hand, as people's incomes rise, consumerism and hedonism are becoming widespread, which has aggravated the problems of environmental degradation, resource depletion, and carbon emission.

3 CHALLENGES AND STRATEGIES

3.1 Challenges in the Innovation and Application of Green Technology

Urban green development has great bearing on the fulfilment of national emissions commitments. Over the past two decades, urban development in China has been moved toward heavy investment, large consumption, and high emissions. Tremendous resources have been invested in the water, energy, and transport sectors. This approach has addressed the supply shortage problem but did not give much consideration to the green transformation of supply and services. In urban planning and land use, the expansion of built-up areas has consumed huge amounts of land and construction materials. As a result, while work and life conditions have improved, the problems of misallocation of land supply, overcrowding of residents and buildings, and an excessive number of high-rises have become more serious. Studies reveal that material production, construction, and operation of buildings in China account for as much as 40% of its total carbon emissions—and this percentage is still rising sharply as urban development continues. It is imperative that China adopt more stringent carbon emission standards and renew its commitment to shifting development mode toward urban green development and wider application of green technologies. That is the path China must take in order to fulfil its "intended national independent contribution" to the Paris Agreement.

Urban development mode is built upon the old approach and short of motives and measures for adopting green development. Under current circumstances, including the fiscal and tax regime and the GDP-based performance assessment method, city governments cannot help keeping economic growth high on their agenda. Cities continue to source capital for infrastructure construction from the proceeds of land supply, instead of actively seeking to change modes and pursue green development. Though green development slogans were occasionally invented, many efforts were aborted once a city faced setbacks. On one inspection tour made by a central government task force to detect environmental breaches, a total of RMB 1.43 billion fines were ordered and over 18,000 cadres were punished. Those figures suggest that local governments haven't done a perfect job on pollution control and the implementation of green development concept.

The lack of scientific evaluation and performance assessment mechanisms has led to the uncoordinated application of green technologies. When green technologies and green products were scaled up, more credit is given to their economic performance over green features. More often than not, they were pitched in “promotion campaigns” that ignore the systematic nature of a city and the life-cycle value flow of green products. Some so-called “green” technologies had not been evaluated on their life-cycle performance and potential externalities before they were commercialized, thus causing waste of resources. Examples to this point include shared bikes and integrated underground corridors. In the “Opinions on Nurturing a Market-Oriented Innovation System for Green Technology” issued by the central government in 2019, it was stressed that a good evaluation system should be established to step up evaluation of green technology, demonstrating the importance of proper evaluation and the urgency to catch up on that front.

Priorities should be set for the whole range of green technologies. Green city and technology have countless aspects, including “technology clusters” in various areas, e.g., material technology, biotechnology, pollutant treatment, resource recycling, clean production, etc. which are relevant to carbon emissions, environment, energy, resources, manufacturing, transport, infrastructure, building, food, land, and other areas. On the other hand, cities are suffering increasingly from problems such as carbon emission, energy consumption and resource depletion, environmental degradation and pollution, heat island effect, big city malaise, etc. Therefore, while a comprehensive approach is needed in promoting green technologies, priorities should be set to address pressing issues and the near-term demands of citizens. Technical breakthroughs can thus be made by selecting key issues and concentrating resources on solving them.

3.2 Green Technology Key Area Identification

The realization of urban green development needs to focus on material green technologies and methods in all aspects of urban planning, construction, operation, and maintenance. There is a need to identify and select green technologies that can solve current outstanding problems while being forward-looking, comprehensive, innovative, and practical.

In order to promote the city's "full process and full chain" green development and ultimately achieve the goal of zero-carbon emissions, we should comprehensively sort out and analyze the green technology system from the four dimensions of "resource protection and utilization, production and construction, consumption and use, decomposition and recycling." Under the dimension, many technical fields are further identified.

Table 4. Main fields of green technology

Resource protection	Production processes	Consumption processes	Decomposition processes
Water resource conservation Economical use of land Sustainable energy Eco capital service Use of meteorological resource urban public space climate adaptation model …	Cyclic economy Energy Technology Manufacturing Technology Construct technology Green Building Material Technology Agricultural Technology Food Production …	Energy structure Energy Supply Technology Transportation Technology Operation and maintenance of buildings Urban infrastructure Food supply chain …	Solid Waste Treatment Technology Water Treatment Technology Waste Gas Purification Renewable resource recycling technology Kitchen waste collection and recycling technology …

The European landmark urban green development program documents: *Aalborg Charter* (1994), *Aalborg Commitment* (2004), *Leipzig Charter: Sustainable European Cities* (2007) and the *Freiburg Charter* (2010) demonstrate that for more than 20 years, energy, transportation, construction, water environment and food (agriculture) have been important areas of low-carbon green development in Europe. In the "European Green Agreement" issued by the European Commission in December 2019, special attention was also paid to energy, construction, transportation, agriculture, pollution prevention, biodiversity, and sustainable industry.

	Aalborg Charter	Aalborg Promise	Leipzig Charter	Freiburg Charter
Core issues and concerns	**Sustainable development of urban economy**: investment to protect existing natural resources **Sustainable land use structure**: promoting the development of efficient public transportation and efficient energy supply, maintaining a humane scale increasing the density, striving to achieve a mix of functions **Sustainable urban transport structures:** giving priority to eco-friendly modes of transport **Avoid pollution of ecosystems:** air, **water,** soil and **food**	**Public natural resources:** renewable energy; efficient use of water; ecological agriculture and sustainable forestry economy **Consumption and lifestyle with a sense of responsibility:** waste reduction and recycling; Improve energy efficiency at the end of consumption **Urban planning and urban development:** transformation and renewal of declining or disadvantaged areas; reasonable urban density to avoid urban expansion; Mix the functions of buildings and development areas priority to residential development in the city centre **Improve the way of travel, reduce the traffic:** reduce the need for private motor vehicle travel; Increase the proportion of public short-distance transport routes to pedestrian or bicycle routes; Promoting the transformation of motor vehicles into vehicles free of hazardous emissions; Formulate comprehensive and sustainable local transport development plans **From local to global:** integrating climate protection policies into relevant strategies and regulations in the field of **energy**, transportation, procurement of waste, **agriculture** and forestry	**Create and secure high-quality public spaces:** **Enhance the modernization of infrastructure networks and improve energy efficiency:** urban transportation systems should be coordinated with regional transportation systems; urban transportation must be coordinated with the functional requirements of housing, employment, environment and public space; Improve energy efficiency; Create compact residential structure ; Stock building in vulnerable urban areas should be improved; **Promote high-performance, low-cost urban transport:**	**Mixed, safe and inclusive cities:** build different living and working spaces for all residents/promote the development of innovative living forms **Short-distance cities:** Facilities and institutions that have good accessibility to cities and regional centers should be further developed. Follow the development concept of "compact, distributed city"; **Urban development/ density model along public short-distance transportation:** increase building density in areas along public short-distance transportation

Focus of SPS5: **Land use and planning**, **energy**, **transportation**, **construction**, **water**, **food**

Figure 3. Four programmatic documents of the European sustainable towns movement

Preliminary research has been focused on analyzing the outstanding problems in various fields and the development needs of green technology, i.e. the innovation and maturity of green technology, the wide range of applications, and the sense of urban residents' gains. As agreed by the Chinese and foreign team leaders, the Chief Counselor of the China Council for

Foreign Cooperation agreed that before May 2020, Green Technology SPS focused its research on the six fields of **water, energy, transportation, building, land use and planning, and food**. In these six fields, single or comprehensive technology screening and evaluation will be carried out, and a list of green technology application promotion lists will be proposed to provide advice and support for the promotion and application of green technologies in Chinese cities during the 14th FYP period.

Table 5. The six key research areas

Areas	**Explanation**
Water treatment and water resources	Protecting water quality, managing water pollution, and promoting recycling, safe and efficient use of water resources
Clean and sustainable city energy	Reduce ore energy use and greenhouse gas emissions, promoting the use of renewable energy and clean energy
Improving city transportation	Promoting green travel, promoting energy conversion and emission reduction of motorized transportation, and optimizing transportation
Developing green building	Promoting the development of high-quality, low-consumption, low-emission buildings and construction technologies
Optimizing land use and planning	Improving land use patterns, optimizing urban layout, building low-carbon communities, and promoting mixed-function planning, and keeping development at a human scale
Urban food production and supply	Exploring city food production systems, protecting biodiversity and urban green production space

Through a comparative analysis of China's and Europe's key policy documents on green development, we believe that it is necessary to systematically analyze and identify green development areas and that the six key areas selected at the first stage are appropriate.

4 MAJOR GREEN TECHNOLOGY ASSESSMENT METHOD

The actual effect of the application of green technology has always been a matter of great concern and continuous debate. The lack of prior and necessary objective assessment in practice combined with blindly promoted green technology has caused a great waste of resources and negative effects. Constructing a comprehensive green technology evaluation system and broad, multi-dimensional valuation of technologies is crucial and urgent for the promotion of green technologies.

4.1 Comparative Study of Evaluation Approaches

At present, there are two mature mainstream approaches in use globally for evaluating green technologies. One is systematic scoring based on a detailed indicator framework, with weight being given to each indicator. Evaluation conclusions are based on the final score. This approach applies mostly to clearly defined evaluation objects. Examples include the U.S.'s

Leadership in Energy and Environmental Design (LEED) standards in green architecture evaluation[1], the DGNB system of Germany[2], the Green Building (GB) Tool in Canada[3], etc. The other approach is framework evaluation, in which the priorities of evaluation are preset with an evaluation framework. This approach is mostly applied to the evaluation of green technologies in the broad sense. For example, the S&P Global Ratings Green Evaluation takes transparency, governance, and mitigation/adaptability as the primary dimensions; under each, there are secondary evaluation items to be scored or rated against[4]. The evaluation is then summarized around the three topics of low-carbon, finance, and governance/management. This approach can be used for seven sectors, including green architecture, green energy, water resource, green mobility, energy efficiency, nuclear energy, and fossil fuel-fired power generation.

The promotion of green technologies in China has mostly taken the form of promotion catalogues, and no evaluation method or system has been established for green technologies. The *Evaluation Standards for Green Architecture* published by the Ministry of Housing and Urban and Rural Development have not been widely applied nor substantiated by the capabilities of professional technical institutions. In the absence of a comprehensive life-cycle all-in-cost evaluation, many so-called green technologies in China have actually created negative impacts such as waste of resource and safety hazards once scaled up. Examples include shared bikes, EVs, and integrated infrastructure corridors.

4.2 Recommended Framework for Evaluation

Evaluation of green technologies should be done based on measures of life cycle and all-in cost to investigate their effectiveness, economic feasibility, scalability of emissions, and consumption reductions as well as user acceptability.

Life-cycle evaluation: Before, during, and after the application. The focus of green technologies should not be just on their application *per se* with no regard given to pre- and post-application green performance. We should use the life-cycle evaluation of green technologies from their conception to scrapping. That is, conception and design, resource pooling, operation, maintenance, decommissioning, and decomposition should be investigated to demonstrate the technology's performance in terms of emissions reductions.

Multi-dimensional, all-in cost evaluation: Incremental cost vs. incremental benefits. When defining the dimensions for green technologies, consideration must be given to economic returns and financial feasibility because that is the foundation for scaling up; in the meantime, the acceptance and recognition from the general public must be considered in addition to the carbon-reduction benefits and economic returns. Benefits should thus be understood as a comprehensive package of economic, environmental, and social returns. In

view of that, we propose a multi-dimensional evaluation framework that covers the aspects of economics, environment, and social, in which the breakeven is defined based on overall cost.

An evaluation framework involving three stages and three core dimensions. The life-cycle evaluation of a green technology covers the three stages of **before, during, and after its application** and the three main aspects—**economic, environmental, and social.** The evaluation makes overall cost and benefits analysis for green technologies through formulating a comprehensive evaluation framework.

The economic dimension looks into the incremental cost and incremental benefits[1] of a green technology in its three stages of before, during, and after the application. The environmental dimension examines the economic returns in terms of emissions cutting and energy conservation in the three stages. The social dimension involves government support, feedback from users/citizens, and willingness of businesses to embrace the technology.

Therefore, the life-cycle evaluation framework for green technologies adopts **quantitative technical assessment in the economic dimension and environmental dimension combined with qualitative assessment in the social dimension**. Recommendations about future promotion will then be made based on the evaluation results.

4.3 The Formulation of Evaluation Procedures

Technical evaluation. In view of the various characteristics of a green technology, technical feasibility should be demonstrated through a quantitative evaluation from the perspectives of economics and environment using a life-cycle approach. First, taking recommendations from industry experts and companies as the main source, absorbing international experience, screen key areas, summarize all known green technologies, and include them in the candidate green technology library to form a long list of green technologies in the field. Secondly, from the three aspects of technology readiness, problem targeting, and promotion feasibility, select the green technologies that are likely to be adopted by the national 14th FYP, to form a list of green technologies. Third, establish quantitative evaluation indicators from the economic and environmental dimensions, forming a four-quadrant matrix evaluation based on carbon reduction and financial evaluation. From this matrix evaluation, a shortlist of green technologies was further selected.

Table 6. Green technology finance—low-carbon evaluation system

	Index Dimension	**Major Index**
Economic dimension-financial evaluation	Incremental cost	Research and design, production, processing and construction, operation and maintenance management, disposal costs, etc.
	Incremental benefit	Resource savings (water savings, energy savings, material savings, land savings, etc.), economic benefits

Environment dimension-low-carbon evaluation	Carbon emission	Amount of carbon emissions
	Environment quality	Emissions of other air pollutants, water and soil environmental impact

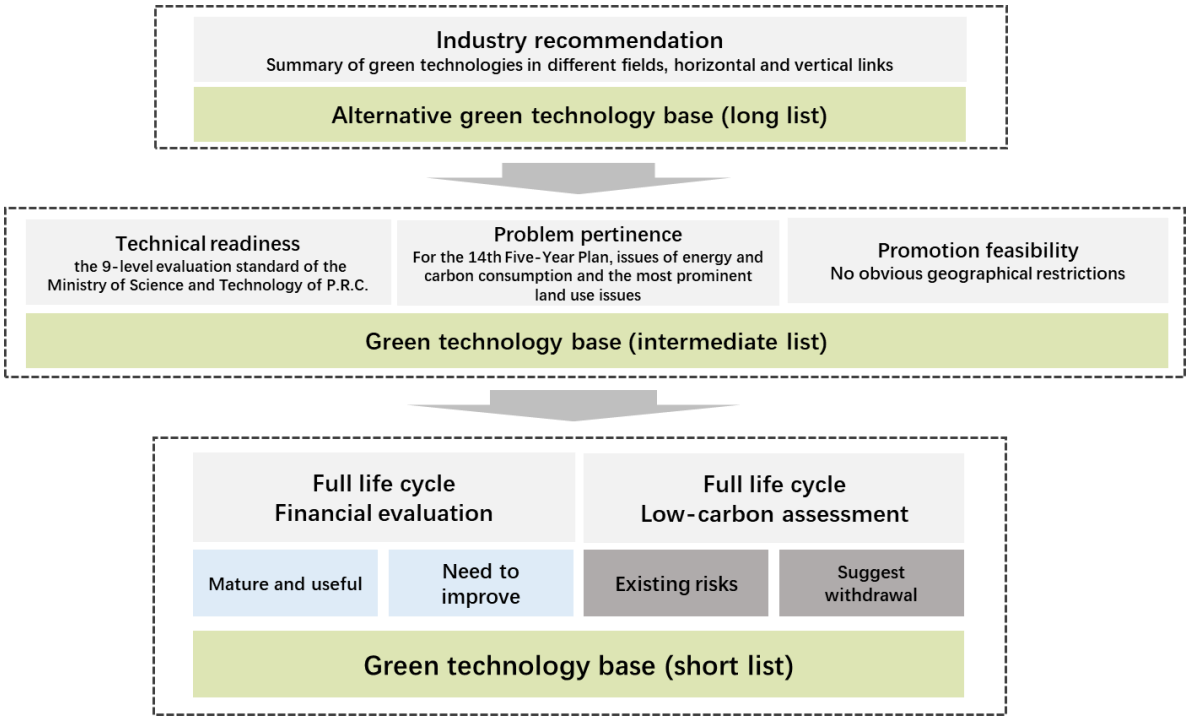

Figure 4. Process of the green technology "long list—intermediate list—short list" 3- steps technology assessment

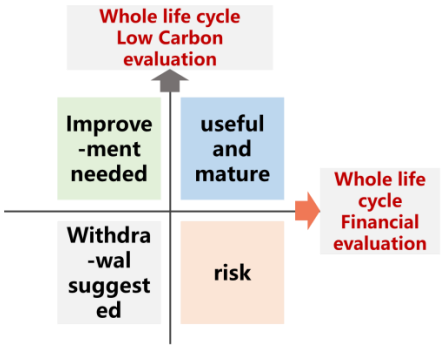

Figure 5. Green technology full life-cycle finance—low-carbon 4-quadrant evaluation system

Technologies recommended. For candidates on the shortlist, a qualitative assessment will be made on the social dimension. Three groups, namely businesses, citizens/users, and industry experts will be consulted for their comments on the candidate technologies. Expert validations will then be synthesized into evaluation conclusions and recommendations: candidates with good prospects for scaling up will be nominated.

Businesses responsiveness: Understand the advantages and hurdles in product manufacturing and/or application of a technology; comprehensively evaluate their acceptance and willingness to adopt a green technology.

Diverse citizens/users acceptability: Collect data from end users on indicators such as comfort, safety, fairness, and convenience; conduct surveys to get feedback on various green technologies in terms of their acceptance and "sense of gaining" by the public.

Government policy: Review existing policies for the degree of support, comprehensively evaluate related resource investments and governance capabilities.

Industry experts validation: Validate the data and process of the evaluation; review the environmental benefits and application prospect of a green technology; propose a final list of recommended technologies.

4.4 Assessment of the Evaluation Methods

Green technology involves many fields, and there are many types of technology with significant differences. In researching this project, the aforementioned evaluation methods have been applied to the green technology recommendation process in the six pillars of water, energy, transportation, construction, land, and food.

In the evaluation stage, it is important to first fully identify the green connotation in various fields, classify it according to its outstanding green utility, and define the technical level that can be evaluated. Second, it is recommended to adjust the specific evaluation indicators of the economic and environmental dimensions according to the specificity of the field. For example, the technical focus in the field of land use and planning should be to improve environmental and life benefits. In addition, highly comprehensive technologies are split into multiple individual technologies, which are evaluated separately and combined afterwards. Third, the focus differs according to each field. For example, assessment of technologies in the field of water and energy focuses on enterprise responsiveness; land use and planning mainly consider government policies and expert evaluations.

5 CHINESE AND FOREIGN EXPERIENCES AND EMERGING BEST PRACTICES

5.1 Water Sector

In terms of the water sector, China has always been faced with problems such as insufficient water resources, uneven distribution of water resources, pollution-induced water shortages

and rapid growth in water demand. Meanwhile, China is also confronted with many challenges, such as the insufficient treatment efficiency of sewage and low utilization efficiency of recycled water. Therefore, the Chinese government launched the "Major Science and Technology Project of Water Pollution Control and Governance"① in 2016, started the work "Pilot of Construction of Sponge City" in 2015 and proposed the "Three-year Action Plan for Quality and Efficiency Improvement of Urban Sewage Treatment" in 2019 which focuses on comprehensively improving the efficiency of the sewage treatment system[5].

Sewage Treatment and Water Recycling Economy. More than 80% of the world's fresh water eventually becomes sewage, and the discharge of sewage that is not managed properly can cause health hazards and a shortage of water resources. Sewage treatment technology consists of a combination of physical, chemical and biological processes to remove solids, organic matter, nutrients and pathogens from sewage. It can solve the problem of water shortages. The byproducts of sewage treatment can generate energy[6], and it can not only enhance a city's water recycling but also decreases the cost of downstream water use[7]. Furthermore, it can recycle up to 90% of the methane gas, which can be used for clean power generation and heating. China has launched an urban sewage treatment program and black and odorous water regulation with carrying out the pilot in 60 cities.

Utilization of Reclaimed Water. Generally, developed countries attach great importance to the utilization of high-quality reclaimed water. The core of the utilization of reclaimed water is the safety of reclaimed water quality. In 2009, Japan published its *White Paper on Sewers*, which stipulates that the government shall strictly control the quality of reclaimed water and regularly disclose the monitoring results to the public, so as to promote the safe utilization of reclaimed water. In Australia, Sydney has adopted a high-tech remote control system to automatically and continuously monitor the operation of recycled reclaimed water to ensure the safety of reclaimed water.

Non-Revenue Water Management (NRW). Non-revenue water is one of the most serious problems of the urban water supply system. It reduces the amount of water that is lost before it reaches the customers by adopting comprehensive methods, including leak detection, pipeline assessment, pressure management and hydraulic modelling. It reduces energy consumption and emissions, and positively affects the financial performance of water utilities by reducing the amount of water lost during conveying, treating, and distributing[8-9]. The International Water Association summarized a series of methods, procedures and evaluation indicators that have drawn broad attention from many water supply enterprises in China to guide the control of the NRW leakage and loss from pipe network.

① Known as the "Special Project of Water" for short, it is listed in the major technical breakthrough project in the outline of national mid- and long-term scientific and technological development planning.

5.2 Energy Sector

For China to achieve its goal of reaching a carbon dioxide emissions peak in 2030, it must control total energy consumption, improve energy utilization efficiency, and vigorously develop renewable energy. Currently, the utilization of new energy technology in China is seeing the rapid development of innovation breakthroughs, industrialization demonstrations, application promotion and demonstration. However, there are still key bottlenecks and obstacles for the safe transmission, distribution, storage, and high-efficiency utilization of new energy.

Integrated Green Energy Grid[10]. This type of grid means that variable supply can be realized through technologies such as solar photovoltaic (PV), wind, battery, and pumped hydro energy storage, smart grids and electricity meters, using abundant wind energy in the winter and solar in the summer to cover heating and cooling demand peaks respectively, using short-term battery storage to account for variable supply and longer-term storage such as hydrogen to solve the problem of the balance of electricity generation and demand during peak and off-peak hours[11]. At present, the application of an integrated green energy grid based mainly on the microgrid in communities has become an important method for solving power problems in countries such as the United States and Japan: demonstration projects in the United States account for about 50% of all global projects[12]. Moreover, the United States, the European Union and the United Kingdom have formulated policies to encourage the scaling of the green grid. Investment in energy storage technology will be key to unlocking the potential of the green grid.

Internet of Energy (IoE). It means that Internet of Things (IoT) technology and processes will be applied to the energy industry to improve energy efficiency and reduce waste. These include smart metering, remote control and automation systems, and smart sensor and demand response systems. According to the International Energy Agency, the IoE can reduce the operating costs of power systems by 2% to 11% and reduce the demand for electricity generation from fossil fuels by 30%[13], which is helpful for improving grid reliability and safety as well as asset utilization.

Near-Zero-Emission Cooling and Heating. This is a technical method that fully considers emission reductions, energy conservation, and pollution reductions in the cooling and heating systems of buildings and industries, including solar power generation for buildings, combined heat and power generation, and waste heat utilization in urban areas, ground source heat pumps in communities, and heat insulation of buildings etc[14]. The geothermal heating in Xiongxian, Hebei Province and Xi'an City, Shaanxi Province are successful practices in China. Near-zero emissions equipment often has higher upfront costs, but are cheaper over its lifetime; for this reason, consumers need to be incentivized by policies to make upfront

investments.

5.3 Transportation Sector

Transportation in urban areas in China faces a prominent mismatch between supply and demand, with problems such as insufficient development of green and intensive transportation, the rapid growth of transportation energy consumption and emissions, and increased air pollution through vehicle emissions[15]. Therefore, China has proposed coping strategies, including promoting the new energy-oriented means of transportation, intelligence and information-oriented development of transportation in urban areas, priority development of public transportation, and sustainable development of transportation.

Intelligent Transportation System. It is the main development direction for the transportation sector in urban areas in China to promote the construction of connected vehicles, IoT and public cloud services, and the in-depth integration of new technologies such as big data, Internet, and artificial intelligence with the transportation sector[16]. In recent years, Europe and the United States have implemented many successful pilots in the seamless integration of the travel system.

New Energy Vehicles and Supporting Facilities. China is promoting the development of electric and new energy-oriented public transport vehicles and vigorously developing blade electric vehicles and supporting charging facilities. Moreover, electric vehicles with hydrogen cells are also a focus of attention. An electric vehicle's emissions are up to 43% lower than a fuel-driven vehicle's[17]. The United States and Japan have applied hydrogen energy to large-capacity passenger service vehicles and heavy freight vehicles and have carried out a large number of technological developments. In Europe, the promotion of electric vehicles through various policy measures in Norway, for example, is a practical case of great value.

Transportation Demand Management and Cycling Trip. This can effectively reduce the number of vehicle trips, alleviating traffic congestion and carbon emissions through the transportation demand management to promote changes in traffic behaviour. Strategies include road pricing, parking pricing, as well as providing better alternatives to driving. For example, China has clearly proposed the strategy of developing the rail transit in a metropolis, giving priority to public transportation, and encouraging shared transportation[18]. The European Union promotes bicycling, walking, public transportation and shared transportation[19]. The European Union also attaches more importance to the demonstration and guidance of the trips by bicycle, and the Bicycle Expressway Project in Copenhagen is a renowned best practice in the world.

5.4 Building Sector

Energy consumption for building operation (20%) and construction (20%) account for about 40% of society's total energy consumption, and this is projected to grow. Therefore, its reduction is a necessity if China is to achieve its low-carbon goal. Meanwhile, with the development of a social economy, the requirements for buildings to be safe, comfortable, and healthy are increasingly higher.

Green Building. This refers to providing a healthy, suitable, and highly efficient building space with saving resources and protecting the environment throughout the entire life cycle. In 2019, China expanded the definition of green building performance from conservation and environmental protection to five aspects: safety and durability, health and comfort, convenience of life, resource conservation, and livable environment, which brought new development prospects.

Near-Zero Energy Building. This refers to adopt passive building design that reduces the need for heating, air conditioning, and lighting by taking advantages of natural conditions and natural forces, or takes active technical measures to maximize the utilization efficiency of energy equipment and systems while creating and fully utilizing the renewable energy and realizing low energy consumption. Developed countries have implemented a large number of practices of near-zero energy buildings and zero-energy buildings, such as the SDE4 building with net-zero energy consumption by the School of Design and Environment, National University of Singapore. In 2019, China issued the *Technical Standard for Near-Zero Energy Buildings*.

Healthy Building. This is a recently emerging technology field that focuses on the characteristics of the building environment that affect human health and welfare, such as air, water, nutrition, light, health, and degree of comfort. In 2012, the United States proposed certification standards for WELL (healthy) buildings. In 2016, China clearly proposed the initiative "creating a green and safe healthy environment and reducing the incidence of diseases"[②] and released the *Assessment Standard for Healthy Building* and *Evaluating Standard for Healthy Housing*. The Chuangye Building in Shenzhen Bay, as one of the optimal practical cases in China, has obtained the certification by WELL.

Smart Operation and Maintenance of Building. A system which carries out the operation, optimization, and control for the building and equipment based on the increased use of AI technology, monitoring and analysis of information such as building environmental quality, energy and water resources consumption, and user needs; it can achieve the energy conservation for equipment and behaviour mode through the digital management and

② Quoted from *Plan of Health China 2030*

providing people with good training to ensure the building is green, low-carbon, and efficient. The "Building Management System" falls into this category. The emerging optimal practices include the Edge Building in Amsterdam and Tencent Binhai Building in Shenzhen.

5.5 Land Use and Planning

In the past 30 years, land in urban areas in China has experienced a series of problems such as excessive expansion, disorderly layout, large-scale demolition and construction, and imbalanced supporting facilities, all of which have affected the ecological environment and the rapid increase in carbon emissions. The planning and control for the scale, form, intensity, network, and node of land in urban areas serve as the source technology to make urban areas green and low-carbon.

Green Urban Form. Advanced cities around the world reduce carbon emission and respond to climate change to achieve green development through the urban planning such as increasing urban compactness, reasonably planning population density and accessibility, a green space layout model, along with mixed land use and transit-oriented development. The optimal practices internationally include the overall planning and urban form control in Copenhagen, Denmark[20].

Green and Livable Block. The practice of green community in international advanced cities mainly revolves around the "3D Principles" (Density, Diversity, Design)[21], which include a series of technical measures such as providing a slow-moving environment, improving the utilization of mixed land, attaching importance to street interconnection and protecting public open spaces, to achieve the building of a livable environment and the reduction of comprehensive energy consumption. The international and domestic emerging optimal practices include the Hammarby Sjöstad community in Stockholm, Sweden, the Gauteng Community in Utrecht, Netherlands, and the China-Singapore Tianjin Eco-City etc.

5.6 Food Sector

China's food supply is not only facing the challenges of increasing food demand, arable land, water resources, climate change and other factors; it is also facing the problems of food security, long-distance transportation, imported animal feed, high food waste rate, malnutrition caused by overnutrition and other urbanization factors. Therefore, the food sector needs to be more closely integrated with urbanization to guarantee green, low-carbon, nutritional, and safe urban food.

Food Traceability. The traceability of foods by technical means can comprehensively track the environmental, economic, health, and social impacts at all stages including food production, sales, and consumption, so as to better identify and respond to food safety issues,

ensure consumers' rights and make enterprises earnestly fulfill the promise of sustainability, support supply chain optimization, reduce food loss, and safety of food supply. This can be achieved, for instance, via the IoT, which enables comprehensive data collection and blockchain tracking, aggregates and shares data from supply chains, and allows food sensing technologies to identify safety and authenticity.

Smart Agriculture. Control and optimize agricultural production, services, and sales through IoT, Internet and AI technology, through such methods as analyzing data, ambient temperature, rainfall, and soil salinity etc. Smart agriculture can realize more thorough agricultural information perception, deeper agricultural intelligent control, and more direct and transparent public services. China has proposed a modern agriculture strategy focusing on "Internet+," and Tencent is actively engaging in the "AI+Agriculture" and has made preliminary progress.

Urban Agriculture. This refers to activities that plant and cultivate agricultural products using the land, water, and building space scattered in various corners of urban areas or suburbs and processes and sells agricultural products with the purpose of satisfying the demand of customers in urban areas. Urban agriculture can enable consumers in urban areas to obtain healthy and nutritious foods while improving the land utilization rate, reducing carbon emissions from food transportation and improving the ecological environment. Urban agriculture is well developed in countries such as Singapore and Japan. For example, Singapore has proposed the "Vision 30.30" action which aims to achieve the goal of self-sufficiency for 30% foods by 2030 through developing urban agriculture.

6 TECHNOLOGY RECOMMENDATION IN THE SIX PILLARS DURING the 14TH FYP

Based on primary technology development directions, considering the outstanding problems in China's water sector, combined with Chinese and foreign practices, Chinese and foreign experts jointly recommend the following green technologies in each sector, during the 14th FYP.

6.1 Water Sector

Technology to improve quality and to increase the efficiency of sewage treatment and the integrated system of plants, networks, and rivers: This technology aims to construct, coordinate, and manage sewage treatment plants, drainage pipe networks, water treatment, sludge resource utilization, bank waste recycling system construction, and reclaimed water utilization, etc. It should solve the problem of low-influent concentration of pollutants in sewage treatment plant while improving the total amount of pollutant emission reduction of

sewage treatment facilities, while ensuring their safe and efficient operation.

This is the intersection of sewage treatment and the sponge city. It not only pays attention to the problems of traditional sewage fields such as sewage treatment plants and water treatment; it is also concerned with the problems of the water recycling economy such as sludge resource utilization and recycled water utilization. Besides, the unified scheduling and management of drainage facilities (as well as the integration with sponge city technologies such as the initial stormwater pollution treatment) are coordinated to solve the problem of sewage collection, so as to improve sewage treatment efficiency.

Smart operation technology of reclaimed water system: Combined with urban topography, reclaimed water utilization and urban land layout, this technology optimizes the service scope, site selection, and water intake mode of reclaimed water plants. Using optimization technology to improve water resource allocation and the pipe network system should help save water resources and reduce energy consumption and operation costs; establish a dynamic simulation system of reclaimed water transmission and distribution based on the digital simulation model; and reduce the leakage of pipe networks while improving operational efficiency.

This is the intersection of reclaimed water and non-revenue water management technology. Through big data analysis and smart simulation methods, it can provide optimized solutions to major problems in the field of reclaimed water, such as service scope, site selection, and water intake methods of reclaimed water plants. Establishing a dynamic simulation system and optimization technology for reclaimed water transmission and distribution can improve the allocation of water resources and the pipeline network system, reducing leakages in the pipeline network, and increasing the benefits of non-revenue water management.

Water quality assurance technology of the reclaimed water system. This establishes an intelligent management and control platform to realize the intelligent management and control of reclaimed water system quality and ensure the reliability of reclaimed water quality, quantity, and pressure. The system is based on model simulation, automation, and big data technology.

This is the most important technology in the field of reclaimed water. It can intelligently and efficiently control the quality of reclaimed water and realize high-quality reclaimed water to supplement urban water supplies. The technology can also establish a water quality traceability and emergency response mechanism for any new coronavirus epidemic situation and other special situations, to ensure the level of disinfectant in the reclaimed water system, in order to respond to major public safety risks.

6.2 Energy Sector

Mid-deep geothermal utilization technology: Through exploration and drilling, geothermal water extraction or underground heat exchange is used to extract underground heat energy, combined with heat exchange and heat pump technology to heat and cool surrounding buildings as necessary.

This is a major technology in the field of near-zero-emission refrigeration and heating. The northern and middle regions of China are rich in geothermal resources, and more than 7 billion square metres of buildings (about 50%) have not yet used clean energy for heating[22]. As a highly efficient and stable clean energy heating method, this technology has broad prospects. In addition, although the construction and installation costs of this technology are high, operation and maintenance costs are low, and the overall economic benefits are superior to heating in large boiler rooms.

Energy Internet-integrated management platform technology: based on blockchain, AI, smart grid, big data, etc., this technology coordinates the relationship between energy supply and demand; a comprehensive service platform is established from the combination of energy planning and design, engineering construction, transmission, and distribution and control, data interaction, energy efficiency monitoring, smart operation and maintenance, and market transactions.

This is the first step in the practice of "energy Internet," and it is also the intersection of integrated green energy grid and energy Internet. On the one hand, the integrated management platform can break the original information island, realize the intelligent energy consumption method of full-service data sharing, and promote the construction of an integrated green energy grid; on the other hand, through Internet technology, it can provide services such as measurement certification, market transactions, energy finance, smart dispatch, and operation optimization, thereby maximizing energy efficiency[23]. In order to enable this technology, there is a need for more dynamic pricing of energy, along with attention to the management of cybersecurity risks.

Microgrid technology: This technology consists of distributed power sources, energy storage devices, energy conversion devices, power distribution facilities, electrical loads, monitoring and protection devices, etc., and is an intelligent DC or AC power generation and distribution system in a certain area.

This is the key technology in the field of integrated green energy power grids[24]. The microgrid features investment savings, green and efficient production, flexible operation, good resilience, integration of power generation and storage, and convenient access and application of renewable energy. It can make up for the shortcomings of traditional large power grids, such as difficulty in peak shaving and poor stability; it is most suitable for new

urban areas and remote areas. China has launched microgrid demonstration applications since 2017.

Industrial waste heat central heating technology: Large-scale industrial enterprises such as power plants will emit a large amount of waste containing more low-grade heat energy during the production process. By extracting the heat energy from the waste, centralized heating can be achieved for the surrounding areas.

This is another major technology in the field of near-zero-emission refrigeration and heating. This technology can make full use of industrial waste heat in China's energy-intensive industries, while effectively controlling environmental and atmospheric pollution and reducing carbon emissions. Using this technology for urban heating does not need to consume a lot of high-quality energy such as natural gas and electricity, and can reduce heating costs and emission reduction pressures. It is a good alternative low-carbon method compared to China's "coal to power" and "coal to gas."[25]

6.3 Transportation.

Mobility as a service (MaaS) technology: Through a single platform and one-stop service, it connects government management departments, links users and transportation companies, and effectively integrates many different transportation resources such as cars, buses, bicycles, sidewalks, and shared transportation. By auto-pricing and other means, it provides travellers with a variety of travel packages.

This is a major emerging technology in the field of smart transportation systems. It is cleaner and more efficient than traditional transportation systems. It can reduce costs and save time while increasing capacity. Studies have shown that with the full implementation of this technology, the cost of a single trip can be reduced by 25% ~35%, capacity increased by 30%, and travel time reduced by 10%. At present, China is advancing the research and development of this technology, and cities such as Shenzhen and Beijing have already carried out pilot projects[26].

Hydrogen energy vehicle technology: A new energy vehicle driven by fuel cells with hydrogen as the main energy source. This technology is a major technology emerging in the field of new energy vehicles and supporting facilities in recent years. At this stage, there are two types: hydrogen energy vehicles and hydrogen energy rail transit vehicles.

Hydrogen energy vehicles rely entirely on hydrogen energy, with zero carbon emissions and no pollution. In addition, it has the advantages of high energy density and conversion rate of hydrogen fuel cells, long life, easy recovery of raw materials, and small space occupied by hydrogenation facilities. Hydrogen infrastructure can also be used for energy storage and to heat homes.

Hydrogen energy rail transit vehicles consist of hydrogen and fuel cells to form a power system. This technology can get rid of the traditional line traction power supply system, reduce investment, and has the characteristics of low noise, low pollution and long service life[27]. Pilot projects for hydrogen energy rail technology have been deployed in the United States, Japan, Spain, and Germany.

Intelligent charging system technology: Based on the IoT, Internet of Vehicles, artificial intelligence, and energy demand management, this technology coordinates the power supply side, charging side, and transmission and distribution network to realize the digitalized, scenario-based and intelligent operation of new energy vehicle charging services. It is composed of intelligent charging pile, vehicle pile network, intelligent charging information management platform and so on.

This is another important technology in the field of new energy vehicles and supporting facilities. The lack of charging supporting facilities is one of the main obstacles for the current large-scale promotion of pure electric vehicles in China. This technology can alleviate the contradiction between supply and demand for vehicle charging, and at the same time better balance the load of the power grid. In the future, through vehicle-to-grid (V2G) technology, electric vehicles will be integrated into the energy storage infrastructure and can give power to the grid during peak times.

Bicycle special road technology: This is a special road facility technology for bicycle traffic. It can be flexibly adopted in the form of elevated or ground layout to ensure the independent special road rights of bicycles.

This is also one of the specific technical practices and applications in the Travel Demand Management (TDM) series of technologies, and has a significant role in improving the bicycle using rate and reducing carbon emissions. According to relevant research, the rate of bicycle trips along the route can be increased by 10%~20%, and carbon emissions can be reduced by 60~70 tons/km per year[28]. In addition, the technology has good social recognition, high comprehensive social and economic benefits, and is urgently needed in China[29]. Beijing, Xiamen, and other cities have already conducted preliminary trials.

6.4 Building Sector

"Steel structure + modular internal space" technology: "Modular internal space" refers to the design of the building as a large column network, high-rise high-standard modules. It can realize the free division of internal space, the separation of building structure and building equipment pipelines, as well as the adaptation of equipment and facilities to changes in functional space, thereby making the building more durable. The steel structure can make a large space that is safe and economical, while also more conducive to the realization of

"modular internal space."

This is one of the key technologies in the field of green building. China newly builds about 2 billion square metres every year. The traditional construction method consumes large amounts of building materials, the construction site environment is poor, the construction time is long, and the construction quality is uneven. As a result, the average lifespan of Chinese buildings is only 30 years. This technology has the advantages of recycling materials, saving building materials, reducing construction waste, reducing on-site operations and workers' needs, improving the construction environment, shortening the construction period, etc., while further solving the problem of space supply and demand matching, and space safety supply, thereby improving building life.

Building three-dimensional greening technology: This refers to the use of building roofs, overhead floors, balconies, window sills, walls and other building parts for greening technology, including plant selection and matching, building structure, maintenance management system, etc.

This is a key technology in the cross fields of green building and healthy building. The density and intensity of urban construction in China are relatively high, and the green space per capita is limited. The development of three-dimensional greening is a realistic choice. This technology has multiple benefits, such as improving building thermal performance, improving building microclimate, beautifying human settlements, and rebuilding biodiversity. Studies have shown that with this technology, the duration of natural ventilation that can be applied to buildings increases by 35.3%, and the cumulative amount of cooling load that can be treated by ventilation increases by 8.81%; the external surface temperature, internal surface temperature, and indoor air temperature of the summer wall of the building are respectively lowered by 21.6 ℃, 5.7 ℃ and 5.2 ℃; the air conditioning power rate can reach 39.97%.

Photovoltaic, building-integrated photovoltaic (BIPV), distributed energy storage, and DC power supply technology: This technology integrates photovoltaic power generation with distributed energy storage and DC power supply in buildings. It is a necessary technology in the field of near-zero energy consumption. It combines the advantages of renewable energy utilization and distributed energy storage to improve energy security and DC power supply to improve energy supply and demand matching.

Photovoltaic distributed energy storage can effectively solve the contradiction between the uncertainty on the power source side and the peak–valley changes on the load side, and realize low-carbon energy. With the improvement of photovoltaic efficiency and cost reduction, as well as the development of battery technology, photovoltaic and distributed energy storage has significant potential for application in buildings. DC power supply has

more advantages in terms of safety, efficiency, reliability, and distributed power supply coordination and constant power supply. At the same time, because of the use of a safe voltage power supply, it is more friendly to children and the elderly. The combination of the two has broad technology and market prospects.

Group intelligent building system technology: This is a new-generation building intelligent platform technology, which realizes intelligent control of the building environment and electromechanical equipment, improves user comfort, improves the operating efficiency of building systems, and reduces building energy consumption. The swarm intelligence system takes the space and source equipment as standardized units and connects them into a computing network covering buildings and cities according to their spatial location. It adopts a decentralized architecture and designing a parallel computer system based on the changing process of the physical field, so that the computing process and the physical field achieve deep integration. In addition, through a self-organizing intelligent community, it optimizes overall functioning.

This is an emerging technology in the field of smart building operations. Existing intelligent building systems generally have problems such as inaccurate correspondence between data and physical systems, a long engineering period, and monitoring without control, which makes it difficult to adapt flexibly to changes in urban systems. Group intelligent building system technology can control electromechanical equipment through monitoring and intelligent algorithms to achieve accurate and efficient matching of building environment supply and demand. Research from other countries shows that relying on swarm intelligence algorithms (including typical particle swarm intelligence algorithms and simplified swarm intelligence algorithms) can reduce building energy consumption by more than 25%, while the construction project cycle is only three to four weeks, with an initial investment cost equivalent to the general building management systems.

6.5 Land Use and Planning

Green city form technology package: This mainly includes two technical tools: urban development boundary delineation and city main function layout along the bus corridor. The delineation of urban development boundaries is mainly through defining the external boundaries of urban growth, strictly controlling the large-scale extensive expansion of cities, and promoting intensive urban development; the main functions of cities are developed along public transport corridors, mainly through the coordinated development of urban functions and public transportation, which increases the overall public transportation trip ratio and reduces the carbon emissions of trips through a rational function layout[30].

The delineation of urban development boundaries can help control the size of the city and

reduce transportation energy consumption. At the same time, it forces more resources to be transferred to the city's internal development, guiding the government and enterprises to phase out high-pollution and high-emission industries, further reducing industrial energy consumption, and improving land use efficiency. From 1990 to 2013, the city of Portland in the United States delineated its development boundary: population growth was cut nearly in half, and carbon emissions fell by 14% (during the same period, carbon emissions in the United States increased by 6%)[31].

Guiding the development of the city's main functions along the bus corridors, locating residents' commuting, shopping, and use of urban public services around public transportation stations, increases residents' willingness to use public transportation and reduces the energy consumption of private cars[32]. Stockholm, Sweden, guides the development of the city's main functions along the bus corridor, allowing more than 60% of residents to use public transportation for travel, much higher than other European cities[33].

Green livable carbon-neutral block technology package: This mainly includes three technical tools: multi-layer high-coverage building layout; street space design of a dense road network in small blocks; and comprehensive implementation of bus-oriented development in combination with public transportation stations. A multi-layer high-coverage building layout limits the height of residential buildings and matches the corresponding floor area ratio and building density indicators, comprehensively using neighbourhood scale optimization, building regression control, and open space optimization methods to achieve a relative balance between residential density and human settlement environment quality. The street space design of the dense road network in small blocks focuses on improving the interconnectivity of streets, increasing road density, creating a comfortable and convenient walking environment, and reducing the use of private cars. Combined with public transportation stations, we will fully implement bus-oriented development to improve the convenience of connecting public transportation in the neighbourhood, the quality of the slow-moving environment on the street, and overall public services in the community.

Compared with high-rise and super high-rise buildings, the multi-layer high-coverage building layout has multiple advantages, such as low life-cycle cost, high quality of human settlement environment, and reduced fire safety hazards. It also helps reduce industrial energy consumption in the construction, operation, maintenance, and demolition processes.

The street space design of the dense road network in small blocks helps create a more comfortable and convenient pedestrian environment, guide residents to choose green transportation, and reduce traffic energy consumption. According to research, for a block of about 1 square kilometre, using this technology, the walking distance of residents from the door of the house to the centre of the block can be reduced by more than 30%[34].

Combined with public transportation stations, comprehensively implement bus-oriented development, guide community service facilities around rails or bus stations, and provide diversified green connection methods to help reduce car use and transportation carbon emissions.

6.6 Food Sector

Food safety information monitoring and tracking technology: Through the integration of a series of technologies such as RFID or electronic QR code information collection, WSN IoT, EPC global product electronic code system, logistics tracking and positioning, etc., comprehensively track and share information of all aspects of food production, sales, and consumption to clarify responsibilities and protect rights and interests.

This is a key technology for the concern of food traceability and is of great significance to food safety and self-discipline in the food industry. This technology can achieve a full record of food information at the production site and circulation links so that it can be documented; at the same time, each link is interlocked to avoid data loss or human intervention in the circulation process, to ensure food safety and reliability. It allows consumers and managers to easily and quickly understand food sources and transportation processes, as well as enhance food safety monitoring.

Vertical agricultural technology: This is a combination of environmental control technology and architectural agriculture integration, that is, in urban buildings, making full use of renewable energy and greenhouse technology, with the help of hydroponic cultivation, modern LED lighting and seed selection and other innovative technologies, to increase agricultural production and land utilization.

This is a major technology for urban agriculture and a popular investment field in developed countries. Vertical farms have the advantages of having a small footprint and high yield per unit area; intensive use of water and fertilizers, no heavy metals and pesticide residues; localized production and distribution to make food fresher, etc., which can achieve efficient planting under resource shortage conditions and meet green food demand. It can also improve environmental efficiency, with multiple benefits. The United States and Japan have already carried out pilot projects, and Singapore has adopted it as one of the main technologies for realizing food self-sufficiency with a target of producing 30% of food within the city by 2030.

Digital food platform technology: This platform will connect the various supply chain links from production to consumption, allowing consumers to directly connect with producers to ensure the fresh and convenient supply of agricultural products and the efficient allocation of resources.

This technology is a major one in the field of transportation and sales in the field of smart

agriculture. Research by the International Food Policy Research Institute shows that from production to consumption, the global food waste rate is as high as about 30% due to the influence of middlemen, but the freshness is difficult to guarantee. This technology can eliminate intermediate links and directly target agricultural products and food procurement. Studies have shown that if implemented properly, the loss rate can be reduced by 50%. In addition, the technology played an important role during the COVID-19.

7 CROSS-CUTTING ISSUES AND ENABLERS ON GREEN TECHNOLOGY PROMOTION

7.1 Fourth Industrial Revolution

The Importance of the Fourth Industrial Revolution for Green Urban Development:

The Fourth Industrial Revolution (4IR) is a confluence of new technologies, including artificial intelligence, robotics, IoT, autonomous vehicles, 3-D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing[35], which is changing the way people live, work, interact, and access urban services. 4IR-enabled cities have the potential to deliver a sustainable future for all. However, positive change is not inevitable, and city leadership must be forward-looking and agile enough to steward this change for the benefit of all society.

In cities, the 4IR can be thought of as the layering of a series of technologies that brings physical infrastructure into the digital realm. Ubiquitous connectivity is provided by the Internet and the high bandwidth of the 5G network; this enables the IoT of a city, which consists of sensors that can detect and digitize everything from the temperature of buildings to leaks in pipes and the prevalence of viruses in wastewater. The digitizing of the physical space creates a digital twin of the city in the form of data streams that can be manipulated using AI algorithms or logged and traded on blockchains. This manipulation of digital data, in turn, controls the physical infrastructure of the city, opening huge possibilities.

The 4IR Supports Green Technology Implementation Across the Six Pillars:

The 4IR can positively affect urban areas in a number of ways: Firstly, the development of mixed land use can significantly benefit from 4IR technologies. For example, AI coupled with online platforms could monitor and adapt spaces based on local citizens' habits and consumer demands.

Second, intelligent urban assets can unlock the **circular economy** potential, reducing waste and improving resource efficiency for societies[36]. The IoT can provide data on the location,

condition and availability of an asset (from the location and availability of a shared bike or the condition of a water pipe), this data enables extending the life of an asset (through predictive maintenance), greater utilization (by sharing) or more use cycles (through product reuse)[37].

Third, as outlined in the **energy pillar**, 4IR technology can enable the transition to a smart grid or the IoE with decentralized renewable power generation systems, including from BIPV.

Blockchain can contribute to resolving **water scarcity**. A blockchain-based smart water market could effectively allocate water resources by providing accounting, auditing and trading platform replacing intermediaries. Based on a study modelled on Los Angeles County, blockchain-enabled trading could reduce water inequality by facilitating water trades between systems with a surplus and those with a deficit. It could also create incentives for wastewater recycling[38].

Fourth, smarter risk forecasting and regenerative materials can anticipate and reduce the hazards of **climate shocks and natural disasters**[39]. Predictive AI analytics, IoT and sensors can help early identification of cities' tremors or sea-level changes[40]. Advanced materials, such as self-healing concrete, can absorb energy and thus help buildings resist earthquakes[41].

Lastly, in the not-too-distant future, a new generation of quantum sensors will also vastly increase what can be sensed and digitized in a city. Quantum sensors are able to measure minute changes in gravitational and magnetic fields by manipulating and sensing atoms. Early uses of these could be the ability to probe deep underground, creating an underground map of where existing pipes and cables are located allowing for better urban **construction** and maintenance; and building better lidar (a base technology for autonomous vehicles) based on photons rather than lasers[42].

Benefiting from the investment capacity and clear long-term vision of the government, China has emerged as a global power in the transition toward 4IR and smart urban development. China is specializing in "breakthrough" innovations and is home to many companies which are experts in AI and 5G technology, such as Huawei, the world's leading telecom hardware provider[43].

So far, 31 Chinese provinces have invested more than USD 7 trillion in 22,000 projects for new smart infrastructure construction. In March 2020, China launched the "New Infrastructure" initiative, including the 5G network, big data, ultra-high voltage transmission, inter-city transportation, artificial intelligence, industrial IoT, and new energy vehicle charging stations.

Governance Approaches to Successfully Implement the 4IR:

The complex, transformative and dynamic nature of the 4IR requires new governance approaches to address the interlinked dynamics of emerging technologies and to accelerate the

positive societal implications of digital transformation while minimizing the potential drawbacks[44]. Over the next few years, Chinese governance will be inevitably called to face two major challenges:

(i) the development of a long-term human-centred vision around technology integration;

(ii) the development of an agile approach to embrace, rather than hinder, innovation.

The rapid technological change of the 4IR calls for a new model of more purposeful technology integration that puts citizens at the centre[45]. For example, in the case of urban sprawl, the advent of the autonomous vehicle might push it to the extreme level by providing the option for people to live much further away and use the commute time to work or sleep. Planners need to anticipate this and plan for more dense cities that serve the population as a whole.

Second, 4IR technologies mature at a rapid pace and therefore require an agile approach to governance, which can involve prototyping new governance structure and mechanism as well as working closely with other stakeholders such as the private sector and academia. China can adopt an agile and proactive approach to harnessing 4IR technologies. Some tools useful for this purpose can be:

Pilot cities: Working with the private sector and academia, policy-makers can use the data gathered in pilot cities to replicate the innovations elsewhere as well as to support policy-making. Pilot cities could be an innovative way of testing the technologies outlined in this report.

Policy labs: Initiatives aimed at designing new policies and public services to steer emerging innovations toward sustainability and inclusion[46].

Regulatory sandboxes: Safe spaces for companies to test innovative products, services, and business models without needing to face the normal regulatory and financial hurdles (i.e., licensing) of engaging in their experimental activities[47]. Examples of jurisdictions and their regulatory sandboxes include Sweden for autonomous vehicles (Drive Sweden), Bahrain for financial technologies, and Singapore for energy innovation[48-50].

7.2 Circular Economy

The Importance of the Circular Economy in Green Urban Development

The circular economy is a system of production and consumption that aims to keep all products and materials at their highest value at all times and in which the output of one process becomes an input to another, eliminating waste from the system and minimizing the need for the extraction of virgin materials while eliminating the use of toxic materials[51]. China was among the first countries in the world to legislate for a circular economy,

implementing the Circular Economy Promotion Law in 2009 and has continued to be a leader in the field. A recent study by the Ellen MacArthur Foundation found that the further application of circular economy principles in Chinese cities could save Chinese consumers RMB 70 trillion (around USD 9.9 trillion) and reduce greenhouse gases by 23% through 2040[52].

Circular Economy Support Green Technologies Across the Six Pillars

The circular economy touches all pillars outlined in the report, as it deals with the flows of resources around a city. These flows are complex systems that intersect across different aspects of the city. Therefore, the implementation of the circular economy is intimately tied to systems analysis and thinking. Illustrations of this approach in food, building, and consumer waste show how various changes at different points of the cycle can shift the whole system.

For example, the urban food system touches on the food, water, mobility, and energy pillar and is a good example of where the circular economy can be applied. Key raw material inputs into food production are nitrogen, phosphorous, and potash, of which China consumed 54.16 million tons in 2015[53]. China is self-sufficient in nitrogen and phosphorus but dependent on potash imports (43.8% dependence in 2017) mostly from Russia, Canada, and Belarus[54-55]. Food then enters the city by truck, affecting mobility by adding to traffic and pollution. Before it is eaten, globally, one third of all calories are lost in the form of food waste either at the transport, processing, or retail stage or in individual households[56].

Under a circular system enabled by green technology, land and water would be used as efficiently as possible with some degree of vertical farming in cities that could be built in under-utilized space in the urban environment and save water by using hydroponics in a closed water system while decreasing traffic from transport. Food waste would be minimized along the value chain and in the home, in part by using digital platforms. Any unavoidable waste would be converted into usable products or processed industrially using anaerobic digestion. This would produce an output of methane gas for renewable energy production and compost to be returned to food production. Sewage sludge can also be harvested and used as an input into agriculture. For example, in the Netherlands, the Amersfoort sewage treatment plant produces 900 tonnes of high-grade fertilizer per annum as well as purifying wastewater for reuse in cities. According to government figures, wastewater in China contains nearly 120,000 tonnes of phosphorus, which could be better captured with the implementation of the right technology[57].

In construction, which globally consumes 42.4 billion tonnes of material per year, there are many interventions and technologies which could better use construction waste, including the 3D printing of new buildings using waste materials. However, the most important lever comes at the design stage. Buildings such as Circl, a mixed-use restaurant and office building in

Amsterdam, are designed and built with eventual disassembly in mind—a concept known as "buildings as material banks." To accompany these buildings and record the valuable materials inside, developers create materials passports; these log a blueprint of the building, including the value and location of valuable components, to allow for easy disassembly and assessment of embedded material value, leading to higher recycling rates. Using recycled steel uses only 16%-20% of the energy of virgin steel, while in the case of aluminum, the number goes down to 5%[58].

At a global level, only 20% of Waste of Electrical Electronic Equipment (WEEE) is formally collected and recycled[59]. These products can be a valuable source of scarce and valuable materials. The global value of WEEE is estimated to be more than USD 60 billion[60]. A study by the World Economic Forum and Tsinghua University found that in China only 10% of aluminum, 6% of tin, 0.6% of cobalt and 0% of rare earths are captured from scrap electronics products. If 100% of these metals were recycled, the material value alone would be worth USD 3.3 billion by 2030[61].

China has also outlined ambitious policies for the circular economy in industry, including recycling of 50% of key products by 2025 and the inclusion of 20% recycled materials in all new products. Many companies with production facilities in China have also made commitments to the circular economy and the use of recycled material in products. There is a significant opportunity for public and private stakeholders to come together around this goal[62].

Incorporating the Circular Economy Into Urban Development Planning

There are a number of ways that the circular economy can be implemented into urban planning and the application of green technology.

Firstly, it is important to have a circular economy plan based on a system analysis of the city. This should outline the opportunities for all stakeholders including startups, research institutes, government departments, urban planners, and the private sector, as well as aiming to engage citizens in the circular economy.

For example, the London Circular Economy Roadmap provides guidance for the acceleration of the British capital's transition to become a circular city. The Roadmap could bring London net benefits worth GBP 7 billion every year by 2036, mainly in the sectors of the built environment, food, textiles, electricals, and plastics[63].

Secondly, policy and taxation should be aligned with the goals of the circular economy. These could include: charges that take into account the negative externalities of single-use items such as plastic bags; tax breaks for the use of recycled materials in products; and incentive mechanisms such as extended producer responsibility. Consider also unproductive policies, such as those which inhibit or tax waste movements in and out of manufacturing zones or

subsidize virgin feedstocks.

Thirdly, facilitate investment with government funds or blended finance models into innovation for the circular economy. Government funding can help de-risk investment in circular business models[64]. Banks can also be encouraged to set up innovation funds (or companies innovation challenges) to spur entrepreneurship.

Governance That Facilitates the Circular Economy

Governance for the circular economy can be complex: as outlined above, material often flows in cities across many different areas and therefore different departments. Changing an entire system to implement the circular economy in cities requires collaboration with many stakeholders including the private sector, responsible for much of the innovation and implementation; citizens, who need to change how they use resources; and academia, who have specialized knowledge. Due to the cross-cutting nature of the circular economy, many cities, regions, or countries have made use of a platform approach which brings together all of the key players in a structured way to collaborate on implementing the circular economy in a city or region or around a particular challenge, examples include:

- The European Sustainable Phosphorus Platform (ESPP): The ESPP works with a diverse range of stakeholders and ensures knowledge sharing; creates network opportunities in the phosphorus management field; and addresses regulatory obstacles[65].
- The Platform BAMB – Buildings as Material Banks – connecting 15 partners from seven European countries to create circular solutions in the building sector. Through design and circular value chains, BAMB aims at increasing the value of building materials. This way, at the end of their life, buildings become banks of valuable materials instead of being wasted[66].
- The Platform for Accelerating the Circular Economy (PACE) is a global convening platform and project accelerator to help speed the transition to a circular economy. It was launched in Davos in 2017 and is now hosted in the Netherlands. The platform provides a leadership platform for CEOs, ministers and heads of international organizations to come together to collaborate; it runs and supports high-impact projects around the world and works with partners on sharing knowledge and learnings[67].
- The Ellen MacArthur Food Initiative brings together key actors to stimulate a global shift toward a regenerative food system based on the principles of a circular economy.

7.3 Data Governance

The Importance of Data Governance for Green Urban Development

Data has been called the "new oil" and is the engine of the 4IR. Each day more than 2.5 quintillion bytes of data are generated, with much of it coming from IoT devices in urban areas. This data is a potentially rich source of information that could be used to improve the delivery of urban services, the management of urban systems, and the quality of life of citizens. Unfortunately, only a very small amount (less than 1%) is used to drive decisions and create value. Data is normally held by many different players, stored on different systems, and lacks interoperability, meaning it is unable to release its full potential to generate immense social and economic value[68]. Building better data governance by creating well-designed, regulated, and trusted frameworks that enable data opening, connection, and sharing has the potential to unlock this enormous social and economic value for cities.

Data Governance Supports Green Technology Across the Six Pillars

There are essentially two types of data generated in cities. **Public sector data** refers to data "generated, collected and stored by international, national, regional and local governments and other public institutions, as well as data created by external agencies for the government or related to government programs and services." **Private sector data** refers to information "generated, collected and owned by private companies or individuals, such as customer activity data, personal data, business operational data and industrial data."[69]

In the case of public sector data, governments can implement open platforms to share data for free, covering critical sectors such as geographical data, climate data, water resources data, road structure, traffic maps, buildings, energy, air pollution, etc[70].

The city of Berlin, as part of its Open Data Initiative, has created an open data platform that has 935 datasets freely available. Within this, datasets on **mobility** cover everything from real-time public transportation data to the location of bicycle accidents. This data platform allows companies to build applications that act as an interface to help citizens navigate the city[71].

Uber Movement, a software app, is giving city planners and members free access to anonymous data gathered from millions of Uber trips in more than 700 cities across the world. The data shared by the software enables urban planners to better address city **mobility** challenges[72].

Creating an IoE will mean that energy utility companies will have to manage not only the energy grid but also a data grid that must be interoperable with IoT devices from

numerous different manufacturers. Smart appliances; smart meters; EVs and renewable energy generated at a building or household level all create data that needs to be understood and analyzed by the utility. Strong data governance and standards will be needed to facilitate sharing between this network of devices, the utilities, and third parties[73].

Governments Should Take Actions to Effectively Implement Data Governance

Effective data governance implementation is possible only if stakeholders trust the data-sharing platforms that are being used. Thus, the proper management of data requires that **necessary restrictions and regulations** are in place[74]. In fact, opening public sector data without restrictions and allowing private sector data-trading activities without regulation could decrease the general level of confidence in data-sharing platforms. Some of the essential elements that characterize a robust data regulatory framework are:

- **Data privacy**, which should be guaranteed throughout the whole process of data collection, sharing, and use;
- **Data security** to avoid cyber threats such as unauthorized access to data and data impairment;
- **Data interoperability**, which allows data sharing and uses across systems, platforms, locations and jurisdictions;
- **Data accountability**, which should be addressed by "validating and declaring the data provider, evaluating for potential bias, securing transparency and traceability of the data source and data flow";
- **Eligibility of operators**, which ensures that whoever operates on the platform has the legal right to do so and is constantly monitored by legislation;
- **Promote further unlocking of value** by creating platforms for the sharing of private sector data to improve green development in cities. While also encouraging companies and industry associations to facilitate the sharing of data[75].

8 GENDER PERSPECTIVES IN GREEN TECHNOLOGY PROMOTION AND IMPLEMENTATION

8.1 The Importance of Gender Perspectives in Urban Green Development

In the UN's "Rio Declaration on Environment and Development," special highlight is placed

on women's significant role in environmental management and sustainable development. Most often, women take charge of the housework, making themselves important users and participants in the sustainable consumption of natural resources. Women also value green, safety, and health more than men—studies show that the penetration of green consumption among women is higher than men. In education, women exert a vital influence on forging and raising green awareness with children. Women also play a part in improving community adhesiveness, thus strengthening the capacity of communities in natural disaster prevention and management.

That said, in the course of achieving urban green development, the fact is that gender perspectives are not always accounted for. Many women feel unsafe around cities, due to challenges such as: public transport systems that are designed primarily to facilitate commuting rather than meeting gender-responsive needs; lack of proper lighting in public places; challenges in sanitary infrastructure etc. These all come down to the absence of consideration of gender perspectives.

8.2 Experience on Adopting Gender Perspective in Urban Development from the International Experience

Transport: Studies by the World Bank suggest that the public transport system is usually designed to meet the needs of working men while ignoring women's need to travel in non-commuting hours. Similarly, most automobiles are designed with male users in mind. For instance, the dummy used in a crash test is modelled after adult men: that is at least part of the reason that the likelihood for women to get injured in a car crash is 73% higher than men[76].

Land use and planning: Mixed land use can reduce travel distance, therefore benefiting citizens who use public transport less frequently (e.g., women). Mixed use can also help women to better balance home caring tasks and their jobs. In addition, better design and management of public spaces will give women a greater sense of safety. To that end, a new tool for urban environment assessment called "women safety audit" has already emerged[77].

Architecture: Indoor temperature should be adjusted to make women feel comfortable. Stairs are often designed too wide or too high that they don't fit the gait of women. A UN report suggests that including gender perspectives in architecture design will only increase the building cost by less than 1%[78].

Other topics that attract attention from the international community include: **mobility** – to facilitate safe, convenient, and affordable mobility in and around cities; **safety and protection from violence** – protect women from practical or perceivable dangers in both public and private domains; **health and sanitary considerations** – lead a positive life in environments free of health risks[79].

8.3 Gender Perspective in Urban Green Development

Creating a gender-responsive environment and realizing the full potential of women is one of the paramount goals for urban green development in China. The key principles in this respect are: know and account for women's role in green development; understand that women and men have equal rights in getting their different needs met; take a gender-sensitive approach in planning activities involving women, etc. Therefore, we define the following three dimensions as the priorities in this regard:

Formulation and governance of green policy: Make sure that women are duly represented in the formulation and decision making of green policy. More women should be encouraged to take part in urban green development and governance. The performance evaluation of green policy should be more gender responsive.

Education and employment on green technology: Women should be provided with more opportunities for professional training and research on green technology. More jobs are to be created for women in the sector of green technology. In the production of green solutions and products, a gender-sensitive policy must be applied.

Consumption and use of green products: Surveys on the demand data of women should be included in green product R&D. In addition, women are encouraged to participate in the promotion and scaling up of green solutions and green products.

8.4 Gender Perspective in the Six Key Sectors

Water: Technologies are developed to ensure good quality and smart management of recycled water and to reduce the technical instability in water treatment. Budget for gender-responsive measures will be embedded in local water resource management. These will help address the issue that women may not be able to use and manage water resources in the same way men do due to their physiological differences.

Energy: Mainstream the gender perspective in energy policy-making. Women do not only have a significant role to play in managing household primary energy use, but also function as facilitators for the technical revolution toward sustainable energy. Women should be better trained in the acquisition, installation, operation, and maintenance of sustainable energy solutions. Moreover, taking advantage of their gender strength, women can promote green technology and clean energy to other women, and educate others in the community on how to use them.

Transport: The different mobility demands of women and men should be regarded as the baseline for transport policy research and the preconditions for transport planning. Women must be better represented in transport decision making and management. In all key processes

in the transport sector, including standard formulation, research, decision making and management, transport service operation, etc., women should be ensured an important part to play.

Architecture: Understand women's differentiated demands for building space; develop technical codes and standards for building design that meet the needs of women.

Land use and planning: Women have dual roles both as working labour and as home carers, so they need more urban and community functions integrated within a limited time frame. In addition, women's opinions should be sought in public engagement for urban planning and community governance decision making so that their needs can be duly addressed.

Food: Women usually have more say in deciding what food to buy and how it is prepared. In the promotion of food safety technology, then, consideration must be given to the different roles, needs, and opinions of women and men, and a women-friendly approach will be adopted in technology design.

9 POLICY RECOMMENDATIONS

9.1 List of Recommended Major Green Technology During the 14th FYP Period

Based on the prominent problems, visions, and goals of green development in Chinese cities, and combined with Chinese and foreign practices and current technical progress, Chinese and foreign experts jointly proposed the technical development direction of six major sectors, and recommended the following 20 technologies during the 14th FYP which shall refer to Table 7 for details.

Table 7. Recommendations for Green Technology in Six Major Sectors during the 14th FYP

Major Sectors	Technical Development Director	Recommended Technology
Water	Sewage Treatment and Water Recycling Economy	Sewage Treatment and Plant, Network and River Integrated Quality and Efficiency Improvement Technology
	Utilization of Reclaimed Water	Water Quality Guarantee Technology for Recycled Water System
	Utilization of Reclaimed Water and Non-Revenue Water Management	Smart Operation Technology for Recycled Water
Energy	Integrated Green Energy Grid	Microgrid Technology
	Near-Zero-Emission Cooling and Heating	Industrial Waste Heat Central Heating Technology
		Middle-deep Geothermal Heating Utilization Technology
	Energy Internet	Integrated Energy Internet Management Platform Technology
Transportation	Intelligent Transportation System	MaaS Travel Service Technology
	New Energy Vehicles and Supporting Facilities	Hydrogen-powered Vehicle Technology
		Intelligent Charging System Technology

	Transportation Demand Management and Cycling Trip	Bicycle Special Road Technology
Building	Healthy Building	Building Three-dimensional Greening Technology
	Green Building	"Steel Structure+Modular Internal Space" Technology
	Near-Zero Energy Building	Photovoltaic, BIPV, Distributed Energy Storage and DC Power Supply Technology
	Smart Operation and Maintenance of Building	Intelligent Building Cluster System Technology
Land Utilization and Planning	Green Urban Form	Technical Package for Green Urban Form
	Green, Livable, and Carbon-Neutral Block	Technical Package for Green, Livable, and Carbon-Neutral Block
Food	Food Traceability	Food Safety Information Monitoring and Tracking Technology
	Urban Agriculture	Vertical Agricultural Technology
	Smart Agriculture	Digital Food Platform Technology

9.2 Policy Recommendations for Green Development and Technological Innovation During the 14th FYP Period

Lessons were drawn from developed countries (e.g., EU members, Japan, the United States) on how they successfully promoted green development at the state level to municipal and then to community levels. Recommendations are therefore made on how China should improve its green development and technological innovation, not least by developing favourable legal, policy, and institutional measures. The recommendations are hereby elaborated from the following four perspectives: legislation, government policy and management, market player contributions, and public engagement.

The National Strategy and Legislative Security:

Green development has become a statement of the country's development strategy. We should also clearly propose the overall national green and low-carbon strategy and the overall goal of low-carbon development. We should also accelerate the construction of related legal systems.

Firstly, a national plan for green development and low-carbon development should be created, which proposes to fulfill the commitments of the Paris Agreement, to achieve the 2 ℃ goal and to move toward a carbon-neutral systemic plan.

Secondly, it is necessary to clarify the total amount of carbon emissions in stages before 2050, to control the target, timetable, and road map for achieving the target, and to break the total amount down according to provinces and cities. Economically developed regions and cities should be encouraged to assume more responsibility for reducing emissions.

Thirdly, we have to accelerate the development of a legal system for green and low-carbon development and resource consumption and emission control. This should encourage cities to formulate and implement carbon-reduction targets, achieve green development, and promote local laws and regulations on green technologies.

The mechanism construction from government perspective:

A complete framework of administrative, fiscal, and tax policy should be built to fully engage the government in promoting, incentivizing, and disciplining green development and green technology.

Put in place a quota system for carbon emissions. In such a system, emissions quotas should be determined based on the existing carbon intensity control program and assigned to various levels from state to provinces to cities and counties. The carbon emissions quota will be included in the emissions cutting program and annual work plan of governments at all levels. The quota system can be piloted in more-developed provinces and cities before being rolled out more widely.

Stress the role of strategic planning as the guidance. Establish an international alliance of green technologies and innovations to build a communication platform for domestic and foreign companies, decision-makers, and expert groups, and promote continuous communication and joint resolution of green development issues in Chinese cities.

The mechanism construction from market perspective:

A healthy market should be nurtured in order to allow businesses to play their due role in promoting green development and green technology.

Encourage the market to lead the trend. The role of businesses as the main market players and the determinant in resource allocation should be respected. A market system that mobilizes businesses to work dynamically on developing green technology and manufacturing green products should be formed.

Enhance financial support. The private sector should be encouraged to partake in the green development course. Fundraising by green technology companies should be made easier. The finance market should uphold green principles and devise a complete green financial system.

Promote research and innovation. A market-oriented green technology innovation system will be developed in order to attract businesses and professional institutions far and wide to join the cause.

The mechanism construction from society perspective:

Citizens and communities will be educated to follow a green lifestyle; the green well-being of cities and communities will be safeguarded and upheld. A green governance system that has extensive engagement with the public will be championed.

Implement the emissions data publication system; expand sources for environment data acquisition; and improve transparency. Catalogues will be published to disclose the environmental performance of businesses and cities. Incentives and punishment will be given according to transparency performance. Statistics from various departments will be integrated

into one platform to put all entities under the monitoring eyes of the general public.

Establish institutional mechanisms that encourage public participation. We need to shift low-carbon green development from administrative management to social governance, to clarify citizens' responsibilities, powers, and interests in protecting the environment, to use social media to explain to the public the importance of the promotion and application of green technologies, and how behaviour changes can achieve better green development, thereby raising the awareness of green and low-carbon development in the whole society. Issue laws and regulations to ensure that the public and social organizations participate in decisions related to low-carbon emissions reduction, and introduce relevant policies to encourage the public and society to participate in green and low-carbon development.

9.3 Policy Recommendations for Green Technology Implementation in the Six Pillars during the 14th FYP Period

On the basis of the overall policy recommendations, combined with the two working methods of technical standards and norms and pilot projects, further specific policy recommendations in six key areas are presented, see Table 8.

Table 8. Policy Recommendations for Green Technology Promotion and Application in Six Major Sectors during the 14th FYP

Sector	**Policy Recommendations**	
Water	Laws and Regulations	Establish a multi-level legal system for reclaimed water and improve management methods for the utilization of reclaimed water.
	Department Policy	Prepare the planning of reclaimed water; propose the plant, network, and river integrated water governance and quality and efficiency improvement mechanism, and establish the management system for reclaimed water; strengthen the inspection of the implementation of urban sewage treatment and drainage regulations, and establish the assessment mechanism for an index of sponge city, sewage treatment, and reclaimed water.
	Technical Standards and Specifications	Improve the classification of sewage treatment and drainage standards and technical standards of facility; revise the standards for the utilization of reclaimed water; prepare the treatment and drainage standards for water pollutants in specific areas.
	Financial Revenue	Provide financial support and VAT relief for energy-saving technology, establish, guide and standardize multiple funding channels, and encourage franchise system and financing methods such as BOT and TOT; endogenous financing methods that obtain funds through various fee collections and tax refunds.
	Pilot Project	Establish the pilot demonstration city for black and odorous water treatment and quality and efficiency improvement of sewage and water-saving city.

Energy	Laws and Regulations	Draw up the Priority Law of Renewable Energy, the Promotion Law of Heating by Renewable Energy, and the Promotion Law of Compulsory Utilization of Renewable Materials for Plastic Packaging Waste
	Department Policy	Establish an organization of low-carbon energy management and technology promotion; promote the high-proportion development of low-carbon energy and form the multi-energy and complementary supply system; vigorously promote the garbage classification, reform of energy product price and carbon tax policy. Establish and implement accountability measures and indicators.
	Technical Standards and Specifications	Establish national standards and service systems for low-carbon energy technology; formulate the carbon emission assessment specifications throughout the life cycle; prepare the comprehensive energy planning; promote the WELL certification standard.
	Financial Revenue	Establish a subsidy mechanism for R&D and pilot applications, expand diversified financing channels, promote the reform of green taxation mechanism, and provide loan guarantees for renewable energy. Introduce a more flexible energy pricing system and implement the feed-in tariff subsidy policy. Innovate the hybrid financing mechanism to mobilize the investment of social capital. Reduce initial costs through fiscal and taxation policies and innovative financial products, and encourage the application of photovoltaic integrated technology.
	Participation of The Public	Guide the public to gradually shift to green energy consumption through publicity and education.
Transportation	Laws and Regulations	Establish the regulation system of hydrogen energy management and safety and the battery recycling management system, and supplement the proposed Promotion Law of Effective Utilization of Resources.
	Department Policy	Strengthen the management of the production, sales, and use of electric bicycles; establish the assessment mechanism for recycling management of lithium battery; promote cross-border alliances of industries such as green transportation, mobile payment and financial industry.
	Technical Standards and Specifications	Formulate technical standards for MaaS travel services, technical specifications for sharing of traffic data resources, technical specifications for safety of electric bicycles, planning specifications and standards for charging facilities, guidelines on planning and layout of battery recycling stations, specifications and standards for planning, construction and management of supporting facilities of hydrogen energy.
	Financial Revenue	Formulate the MaaS freight price system and subsidy policy, tax preferential policy for R&D of new battery technology, tax preferential policy for R&D of preparation technology, storage technology and transportation technology of hydrogen energy; set up special subsidy for the construction of infrastructures of hydrogen energy and special funds for the construction of special roads for bicycles.
	Pilot Project	Promote the demonstration project of MaaS travel service and the demonstration project of special roads for bicycles. Promote the use of zero-emission traffic areas and congestion charging pilot projects.
	Participation of	Strengthen the guidance for the public and establish the sharing

	the public	and open mechanism of travel service data.
Building	Department Policy	Implement the target of dual control for total energy consumption and energy consumption intensity; implement the planning of performance goal system and multi-objective optimization for green building project, and establish the smart operation and maintenance system; include the air quality indicators in the completion acceptance process (or combine with the inspection procedures of fire protection); establish the management methods for cyclic utilization of building materials and clarify the main responsibilities of all parties involved in the construction and supervision of green buildings.
	Technical Standards and Specifications	With reference to LEED and WELL, include the performance target, total energy consumption and intensity indicators of green building into the urban planning standards, and formulate the technical standards for pre-planning and post-assessment of green building and guidelines of adaptive design of building; formulate the action plan of green building and prefabricated building during the 14th FYP.
	Financial Revenue	Include the individual purchase of and residence in (including the lease of) green building into the special deduction for personal income tax, and formulate the tax preferential policy for enterprises in using green buildings.
	Pilot Project	Build the pilot demonstration city/urban area with buildings of near-zero energy consumption, demonstration project of near-zero carbon emission zone and pilots of energy-saving transactions of public building.
Land Utilization and Planning	Laws and Regulations	Establish the Development and Protection Law for Space of National Land and the Natural Reserve Law, and grant the legal status to urban design.
	Department Policy	Establish a quick-response mechanism for rules and regulations and price adjustment, and formulate the stipulations for intensive and intensive utilization of land, the disposal methods for idle land and the management methods for land reserve; implement supervision, inspection and full-process management for high-rise residential projects; establish the planning assessment and supervision system for the planning of a low-carbon pilot city and pilot community, and the performance assessment and dynamic assessment system for industrial land.
	Technical Standards and Specifications	Formulate relevant standards and norms for mixed utilization of land, guidelines and relevant norms for construction of residential areas, and planning standards for low-carbon and emission-reducing city/community/public space; formulate relevant guidelines to ensure the connectivity of blocks in terms of community services such as planning, design, construction and management.
	Financial Revenue	Study and formulate environmental tax policy to encourage environmentally friendly development for land
	Pilot Project	Build the pilot demonstration city/urban area with buildings of near-zero energy consumption, the demonstration project of near-zero carbon emission zone and the pilot of energy-saving transactions of public building.
Food	Laws and regulations	Establish laws to guarantee the basic quality standards of farmland soil and water environment; improve the legal guarantee of the food safety and tracking system.

	Department Policy	Promote the whole process management of food from the place of production to consumers, establish a traceability system for the development of the entire industrial chain of agricultural products; strengthen the construction of rural broadband networks, establish agricultural product information platforms, improve the links between farmers and the market; develop e-commerce for farmers Skills training on the platform; formulate policies to promote the conversion of abandoned land and brown land in suburbs into smart agricultural land.
	Technical Standards and Specifications	Establish green food standards for the entire life cycle; develop technical guidelines for vertical agriculture.
	Financial Revenue	Establish a fiscal transfer mechanism for regional fair price payment; formulate a tax incentive policies for the production and consumption of green food.
	Pilot Project	Promote the township/village pilot of green food safety information and tracking technology; establish a pilot community and evaluation system for vertical agriculture.

9.4 Policy Recommendations Based on International Best Practices

The policy recommendations based on international best practices aim to support greater efforts to strengthen the people-centric urban green development goals that promote eco-sustainability, resilience, equity, and quality of life—while also helping steer the Chinese economy toward high-quality growth, particularly through investment in new infrastructure and green technology.

Create guidance for city- and building-level design. Develop a guide for green and low-carbon development and transit-oriented development in Chinese cities; set and promote a standard for green buildings based on best international practices.

Invest in new urban infrastructure. Continue with the New Infrastructure plan to help stimulate the economy post COVID-19. Add three key urban green technologies to the list of new infrastructure investments: building-integrated photovoltaic (BIPV), water treatment technology and energy storage, with ambitious targets for each. In order to build an integrated green energy grid (IGEG), double annual investment in wind, solar, and energy storage.

Continue to drive the adoption of electric vehicles. Strengthen the construction of electric vehicle infrastructure; focus on promoting the electrification of high-mileage commercial vehicles, promote shared vehicles, and implement transport demand management.

Promote digital innovation along the food value chain. Enable robust innovation ecosystems, apply digital innovation to the whole food value chain, improve traceability in food supply chains, produce and adopt healthier, more nutritious and sustainable diets, and promote urban indoor farming.

Build carbon-neutral communities. Make clear targets and a shared roadmap for

carbon-neutral, circular communities, mobilize government departments, the private sector and all stakeholders to participate in the construction of carbon-neutral and circular communities.

Delivery mechanisms. Three strategies that will help to achieve a green transition in Chinese cities include: Pilot cities and policy sandboxes; a cross-border alliance on green technology and engagement with the public.

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References

[1] https://www.cement.org/sustainability/leadership-in-energy-design-(leed)
[2] https://www.dgnb.de/en/
[3] http://www.gbtoolsltd.com/
[4] Standard & Poor's Financial Services LLC，Global Ratings Green Evaluation Report，2017
[5] China Statistical Yearbook (2018). Available at: http://www.stats.gov.cn/tjsj/ndsj/2018/indexeh.htm
[6] M. Swilling, M. Hajer, T. Baynes, J. Bergesen, F. Labbé, J.K. Musango, A. Ramaswami, B. Robinson, S. Salat, S. Suh, P. Currie, A. Fang, A. Hanson, K. Kruit, M. Reiner, S. Smit, S. Tabory (2018), "The Weight of Cities: Resource Requirements of Future Urbanization", A Report by the International Resource Panel. United Nations Environment Programme, Nairobi, Kenya. Available at: https://www.resourcepanel.org/reports/weight-cities
[7] Nutrient Platform, "Phosphorus From Wastewater In Amersfoort". Available at: https://www.nutrientplatform.org/en/success-stories/phosphorus-from-wastewater-in-amersfoort/
[8] New America, "The Development of Smart Water Markets Using Blockchain Technology". Available at: https://www.newamerica.org/fellows/reports/anthology-working-papers-new-americas-us-india-fellows/the-development-of-smart-water-markets-using-blockchain-technology-aditya-k-kaushik/
[9] Great Lakes Echo (2020), "Water sensors, data collaboration make Great Lakes smarter". Available at: https://greatlakesecho.org/2020/02/21/water-sensors-data-collaboration-make-great-lakes-smarter/
[10] 国际能源署. 2010 能源技术展望: 面向 2050 的情景与战略[M]. 北京:清华大学出版社, 2011.
[11] 国际能源署. 追踪清洁能源进展 2017. 北京：科学出版社，2018:17-61.
[12] 王成山, 周越,"微电网示范工程综述",供用电, 2015 年 1 月.
[13] 国际能源署(2019)，"中国电力系统转型"，https://www.iea.org/reports/china-power-system-transformation
[14] 住房和城乡建设部.《建筑节能与绿色建筑发展"十三五"规划》建科[2017]53 号.2017 年 3 月 1 日
[15] 《中国机动车环境管理年报》，中华人民共和国生态环境部发布；http://www.gov.cn/guoqing/2019-04/09/content_5380744.htm 2020 年 3 月 5 日检索
[16] 《绿色出行行动计划（2019-2022 年）》，交通运输部等部门印发；http://www.gov.cn/xinwen/2019-06/03/content_5397034.htm 2019 年 10 月 3 日检索
[17] Global EV Outlook 2019:Scaling-up the transition to electric mobility，May 2019 https://www.iea.org/reports/global-ev-outlook-2019 2019 年 11 月 25 日检索
[18] 《交通强国建设纲要》，中共中央、国务院印发；http://www.gov.cn/zhengce/2019-09/19/content_5431432.htm 2019 年 11 月 8 日检索
[19] European MaaS Roadmap 2025. MAASiFiE project funded by CEDR；https://www.researchgate.net/publication/317416483_Deliverable_2_European_MaaS_Roadmap_2025_MAASiFiE_project_funded_by_CEDR/link/5939f82baca272bcd1e29417/download 2019 年 8 月 11 日检索
[20] 刘志林，秦波，"城市形态与低碳城市:研究进展与规划策略"，《国际城市规划》，2013 年 02 期
[21] Robert Cervero，"TOD 与可持续发展"，《城市交通》，2011 年 01 期
[22] 林伯强. 中国能源发展报告 2018. 北京：北京大学出版社, 2019.
[23] 国家发展改革委,国家能源局.《能源技术革命创新行动计划（2016-2030 年）》发改能源[2016]513 号.2016 年 4 月 7 日
[24] 国家发展改革委.《国家重点节能低碳技术推广目录（2017 年本，节能部分）》.国家发展改革委公告 2018 年第 3 号.2018 年 2 月 28 日
[25] 国家发展改革委,国家能源局.《能源发展"十三五"规划》发改能源[2016]2744 号.2016 年 12 月 26 日
[26] Interoperable Transit Data: Enabling a Shift to Mobility as a Service. Rocky Mountain

Institute,October 2015. http://www.rmi.org/mobility_ITD 2019 年 9 月 21 日检索

[27] The Future of Hydrogen:Seizing today' s opportunities,Report prepared by the IEA for the G20,Japan,June 2019. https://webstore.iea.org/download/direct/2803 2019 年 12 月 21 日检索

[28] CO2 EMISSIONS FROM FUEL COMBUSTION Highlights(2019 edition)，International Energy Agency；www.iea.org 2019 年 9 月 1 日检索

[29] 《中国城市步行友好性评价》，自然资源保护协会和清华大学建筑学院联合发布；http://nrdc.cn/Public/uploads/2017-12-15/5a336e65f0aba.pdf ； 2019 年 9 月 23 日检索

[30] 张杰、杨阳、陈骁、毛其智，“济南市住区建成环境对家庭出行能耗影响研究”，《城市发展研究》，2013 年 07 期

[31] 波特兰：环保和经济可以兼得，《经济参考报》2016 年 7 月 25 日 第 A04 版

[32] 姜洋、何东全，ZEGRAS Christopher，“城市街区形态对居民出行能耗的影响研究“，《城市交通》，2011 年 09 期

[33] 潘海啸，“面向低碳的城市空间结构——城市交通与土地使用的新模式“，《城市发展研究》，2010 年第 01 期

[34] 申凤，李亮，翟辉，“密路网,小街区”模式的路网规划与道路设计——以昆明呈贡新区核心区规划为例，《城市规划》，2016 年 05 期

[35] The World Economic Forum (2016), “The Fourth Industrial Revolution: what it means, how to respond”. Available at: https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/

[36] Ibid.

[37] The World Economic Forum (2016), “Intelligent Assets Unlocking the Circular Economy Potential”. Available at: http://www3.weforum.org/docs/WEF_Intelligent_Assets_Unlocking_the_Cricular_Economy.pdf

[38] New America, “The Development of Smart Water Markets Using Blockchain Technology”. Available at: https://www.newamerica.org/fellows/reports/anthology-working-papers-new-americas-us-india-fellows/the-development-of-smart-water-markets-using-blockchain-technology-aditya-k-kaushik/

[39] The World Economic Forum (2018), “Harnessing the Fourth Industrial Revolution for sustainable emerging cities”. Available at: http://www3.weforum.org/docs/WEF_Harnessing_the_4IR_for_Sustainable_Emerging_Cities.pdf

[40] Ibid.

[41] Flextregrity. Available at: http://www.flextegrity.com/

[42] Battersby (2019), ”Core Concept: Quantum sensors probe uncharted territories, from Earth’s crust to the human brain” PNAS August 20, 2019 116 (34) 16663-16665; https://doi.org/10.1073/pnas.1912326116

[43] The Economist (2018), “Chinese Tech vs American Tech: which of the world’s two superpowers has the most powerful technology industry?”. Available at: https://www.economist.com/business/2018/02/15/how-does-chinese-tech-stack-up-against-american-tech

[44] The World Economic Forum (2018), “Agile Governance: Reimagining Policy-making in the Fourth Industrial Revolution”. Available at: http://www3.weforum.org/docs/WEF_Agile_Governance_Reimagining_Policy-making_4IR_report.pdf

[45] The World Economic Forum (2018), “Rethinking Technological Development in the Fourth Industrial Revolution”. Available at: http://www3.weforum.org/docs/WEF_WP_Values_Ethics_Innovation_2018.pdf

[46] https://openpolicy.blog.gov.uk/category/policy-lab/

[47] https://openpolicy.blog.gov.uk/category/policy-lab/

[48] https://www.drivesweden.net/en and https://www.testsitesweden.com/en/projects-1/driveme

[49] http://www.cbb.gov.bh/assets/Regulatory%20Sandbox/Regulatory%20Sandbox%20FrameworkAmended28Aug2017.pdf

[50] https://www.ema.gov.sg/Sandbox.aspx

[51] World Economic Forum and Ellen MacArthur Foundation (2014), “Towards the Circular Economy” http://www3.weforum.org/docs/WEF_ENV_TowardsCircularEconomy_Report_2014.pdf

[52] Ellen MacArthur Foundation (2018), "The Circular Economy Opportunity for Urban and Industrial Innovation in China". Available at: https://www.ellenmacarthurfoundation.org/publications/chinareport
[53] J, Cai, X. Xia, H. Chen, T. Wang, H. Zhang (2018), "Decomposition of Fertilizer Use Intensity and Its Environmental Risk in China's Grain Production Process". Available at: https://www.researchgate.net/publication/323152227
[54] S. Dong (2019), "Reduce Potash Import Dependence in China". Available at: https://iad.ucdavis.edu/sites/g/files/dgvnsk4906/files/inline-files/Sisi%20Dong_capstone%202019_1.pdf
[55] GPCA (2018), "China Fertilizer Industry Outlook". Available at: https://gpca.org.ae/wp-content/uploads/2018/07/China-Fertilizer-Industry-Outlook.pdf
[56] FAO (2020), "Food Loss and Food Waste". Available at: http://www.fao.org/food-loss-and-food-waste/en/
[57] China Statistical Yearbook (2018). Available at: http://www.stats.gov.cn/tjsj/ndsj/2018/indexeh.htm
[58] BAMB (2019), "Metals Value Chain Report". Available at: https://www.bamb2020.eu/wp-content/uploads/2019/02/Metals-Value-Chain.pdf
[59] ITU (2017), Global E-waste Monitor, https://www.itu.int/en/ITU-D/Climate-Change/Pages/Global-E-waste-Monitor-2017.aspx
[60] World Economic Forum (2019), "A New Circular Vision for Electronics". Available at: http://www3.weforum.org/docs/WEF_A_New_Circular_Vision_for_Electronics.pdf
[61] World Economic Forum (2019), "Recovery of Key Metals in the Electronics Industry in the People's Republic of China". Available at: https://www.weforum.org/reports/recovery-of-key-metals-in-the-electronics-industry-in-the-people-s-republic-of-china
[62] World Economic Forum (2019), "Recovery of Key Metals in the Electronics Industry in the People's Republic of China". Available at: https://www.weforum.org/reports/recovery-of-key-metals-in-the-electronics-industry-in-the-people-s-republic-of-china
[63] LWARB (2017), "London's circular economy route map". Available at: https://www.lwarb.gov.uk/wp-content/uploads/2015/04/LWARB-London%E2%80%99s-CE-route-map_16.6.17a_singlepages_sml.pdf
[64] World Economic Forum (2019), Harnessing the Fourth Industrial Revolution for the Circular Economy Consumer Electronics and Plastics Packaging . http://www3.weforum.org/docs/WEF_Harnessing_4IR_Circular_Economy_report_2018.pdf
[65] European Sustainable Phosphorus Platform, "About the European Sustainable Phosphorus Platform (ESPP)". Available at: https://www.phosphorusplatform.eu/platform/about-espp
[66] BAMB (2020), "About BAMB". Available at: https://www.bamb2020.eu/about-bamb/
[67] About PACE (2020) accessed at: https://pacecircular.org/
[68] SmartImpact (2018), "Data Governance & Integration for Smart Cities". Available at: https://smartimpact-project.eu/app/uploads/2018/02/SmartImpact_Data-Gov-and-Intergration_A4_AW.pdf
[69] World Economic Forum (Forthcoming), "Protocol - Unlocking the shared value of dynamic IoT data in smart city with trusted platforms".
[70] Public sector data refers to data "generated, collected and stored by international, national, regional and local governments and other public institutions, as well as data created by external agencies for the government or related to government programs and services". Source: World Economic Forum (Forthcoming), "Protocol - Unlocking the shared value of dynamic IoT data in smart city with trusted platforms".
[71] European Data Portal (2017) "Analytical Report number 6" Available at: https://www.europeandataportal.eu/sites/default/files/edp_analytical_report_n6_-_open_data_in_cities_2_-_final-clean.pdf
[72] Uber Movement. Available at: https://movement.uber.com/?lang=en-US
[73] Kotagiri, Sunil (2019) "Data Quality and Governance Critical for Utilities" Available at: https://www.tdworld.com/smart-utility/data-analytics/article/20972300/data-quality-and-governan

ce-critical-for-utilities
[74] World Economic Forum (Forthcoming), “Protocol - Unlocking the shared value of dynamic IoT data in smart city with trusted platforms”.
[75] World Economic Forum (Forthcoming), “Protocol - Unlocking the shared value of dynamic IoT data in smart city with trusted platforms”.
[76] Including Gender in the World Bank Transport Strategy, World Bank, 2006, http://documents.worldbank.org/curated/en/968841468147567926/pdf/841800WP0Trans0Box0382094B00PUBLIC0.pdf
[77] Women’s safety audits, what Works and Where? UN-Habita, 2009, Available at: https://unhabitat.org/womens-safety-audit-what-works-and-where
[78] Disabilities, Office of the High Commissioner for Human Rights, United Nations, 2007, https://www.ohchr.org/Documents/Publications/training14en.pdf
[79] ‘Sorry, we didn’t take women’ needs into consideration during product design’, March 9th, 2020. Avaiable at: https://xw.qq.com/cmsid/20200310A000I900