CCICED

SPECIAL POLICY REPORT

Major Green Technology Innovation and Implementation Mechanisms （Phase II）

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Special Policy Study Members*

SPS Chinese Team Leads:

Xiaojiang Li, Former President of China Academy of Urban Planning & Design, National Engineering Survey and Design Master, Member of Beijing-Tianjin-Hebei Collaborative Development Expert Advisory Committee

Qi Zhai, Executive Secretary of the China Business Council for Sustainable Development, CCICED Special Advisor

SPS International Team Leads:

Dominic Waughray, Former Managing Director, World Economic Forum, CCICED Special Advisor

Dirk Messner, President, German Environment Agency, CCICED Council Member

Chinese Core Experts:

Wang Kai, President, China Academy of Urban Planning & Design

Qing Ye, President, Shenzhen Institute of Building Research

Kun Zhan, Chief Expert, China Business Council for Sustainable Development

Xiaobei Lv, Chief Planner, West Branch of China Academy of Urban Planning & Design

Yongbo Zhang, Vice President, Shanghai Branch of China Academy of Urban Planning & Design

Sufeng Wu, Director, Institute of Urban Transportation, China Academy of Urban Planning & Design

Xiyan Ren, Chief Engineer, Institute of Ecology & Infrastructure, China Academy of Urban Planning & Design

Baojun Wei, Deputy Chief Engineer, Institute of Ecology & Infrastructure, China Academy of Urban Planning & Design

Jun Zhou, Director, Shenzhen Branch of China Academy of Urban Planning & Design

Chunhui Ge, Director, Shenzhen Branch of China Academy of Urban Planning & Design

Yongcong Guo, Senior Engineer, Shenzhen Institute of Building Research

International Core Experts:

Lin Boqing, Dean, China Institute for Energy Policy Studies, Xiamen University and World Economic Forum Energy & Materials Platform Steward

Lin Jiang, Nat Simons Presidential Chair in China Energy Policy, Lawrence Berkeley National Laboratory

Khee Poh Lam, Dean, School of Design and Environment, National University of Singapore

Fan Shenggen, Chair Professor, China Agricultural University

Charles Godfray, Director, Oxford Martin School, University of Oxford

Arjan Harbers, Researcher, PBL Netherlands Environmental Agency

Carlo Ratti, Director, SENSEable City Lab, MIT

Claudia Sadoff, Executive Management Team Convener and Managing Director, Research Delivery and Impact, CGIAR System Organization

Barbara Lenz, Head of the Institute, German Aerospace Center (DLR), Institute of Transport Research

Advisory Expert:

Yi Li, National Engineering Survey and Design Master, Deputy General Manager of Beijing Municipal Engineering Design and Research Institute Co., Ltd.

Jifu Guo, President of Beijing Transportation Development Research Institute

Christian Stärz, Head of Biodiversity and Environment, Director Sino-German Environmental Partnership, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

Yehao Song, Professor of Tsinghua University, Director of Institute of Architecture and Technology, School of Architecture

Lin Fu, Professor of Tsinghua University, Doctoral Tutor

Li Fang, Representative of China, World Resources Institute

Degao Zheng, Vice President of China Academy of Urban Planning & Design

Jing Zhang, Deputy Chief Planner, Director of Operation Management Department, China Academy of Urban Planning & Design

Coordinators:

Jingjing Hu, Deputy Director, Academic Information Center, China Academy of Urban Planning & Design

Qiuping Li, Lead, Emerging Markets and Climate Action, World Economic Forum

* The team leaders and members of this SPS participate in the research as individuals and do not represent the views of their organizations.

Executive Summary

The CCICED SPS Major Green Technology Innovation and Implementation Mechanisms Phase I focused on the challenges, opportunities, and solutions in energy, building, mobility, water, land use and planning, and food in the context of green urbanization. The study proposes a list of green technologies to be deployed in large sale during the 14th Five-Year Plan, as well as the enabling environment for implementation mechanisms. In Phase II, the study continually explored the deployment mechanisms at community and urban system levels, including how digitalization is a key enabler for sustainability and climate actions.

Community and neighborhood renewal will become the main approach to urban renewal in China. From international experience, the improvement of residents' quality of life generally pushes up carbon emissions per capita, and the essence of community renewal and renovation is to improve residents' quality of life, and thus there is a possibility of a large rise in China's future community/living carbon emissions.

Based on this understanding, in this study, the study focused on the implementation of green technology applications in the neighborhood; within the limitations of existing research and data, factors such as community location and green technology were taken into account. Five communities in four cities (Shanghai Shibojiayuan Community, Jingjiangyuan Community, Chongqing Hongyupo Community, Shenzhen Heyi Community, and Jiangshan Dongtang Community) were selected as pilots to quantitatively analyze carbon emissions in a comprehensive manner. The current situation of carbon emissions is analyzed, and the future development trend of carbon emissions and the difficulties of decarbonization are identified. Based on the understanding of the differences in strategies and the diversity of communities, the study produced the following major results: 1) green technology recommendations in the fields of building, energy, transportation, and municipalities; 2) pioneering integrated solutions for green transformation for various typical community types in China; 3) recommending a number of new technologies with potential between 2030 and 2060; 4) comprehensively proposing specific approaches for green transformation in communities to shape green lifestyles.

The integrated nature of the urban ecosystem and the fast development of digitalization require a collective, multi-sectoral action to accelerate the green transition at the system level via an integrated approach. Further, the project team conducted more than 20 interviews with representatives from the business sector to provide insights on how the business sector can play a key role via public-private collaboration to accelerate the green transition. The study concluded the challenges, such as technical, regulatory, and social barriers, and the enabling environment for green transformation at the system level, such as strategic planning, multi-stakeholder collaboration, international collaboration, policy, and financial instruments, as well as the culture of innovation and public awareness.

Digital infrastructure, ICTs and datafication are important enablers for urban transformations. The study exmined the opportunities for the green and smart transition by the confluence of physical and digital infrastructures in cities in five dimensions: infrastructure, economy, governance, people, and environment, as well as the risks and challenges associated with the digitalization and dataficaton of cities in each dimensions. Finally, an enabling environment that includes urban sustainability strategies, data governance, citizen participation, experimental spaces, capacity building for local authorities as well as finance mechanisms, is highlighted

Finally, green and low-carbon urban renewal and community transformation are closely related to achieve equity, justice, and shared prosperity in cities.The study proposed principles for green community transformation, especially from the vulnerable, such as women, elderly, children, and low-income groups.

Last but not least, the study proposed a series of policy recommendations for promoting carbon neutrality and green renewal at both city and community levels, based on the results of joint participation and discussions among communities, enterprises, and experts from China and internationally

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FORWORD

To reach the carbon neutrality goal, systemic, intensive interventions in cities need to be carried out as soon as possible. In September 2020, President Xi Jinping promised in the General Assembly of the United Nations that China will achieve carbon neutrality before 2060. This means that a brand-new, stage will be opened in China's social and economic development. Data shows that cities are the leading end-users in energy consumption, accounting for over 85%. In Chinese cities, energy consumption and carbon emissions with production as the main source will be replaced with living consumption as the main source, as the economy goes through structural transformation. Carbon neutrality can be achieved only by systematic change.

The Chinese mode of urbanization has changed from expansion development to urban renewal. The national 14th Five-Year Plan outline explicitly puts forward the acceleration of urban renewal. Therefore, paying attention to community green renewal is an important topic for discussion on the sustainable development of cities.

Community green renewal requires analysis of the actual situation on carbon emissions and prediction of future trends. A rational, effective decarbonization scheme can be designed only through data analysis and demand forecasting of actual carbon emissions in case-study communities. International experience indicates that after GDP per capita reaches 10,000 USD, energy-resource-consumption growth is the fastest. There is currently still a large gap in urban resident consumption between China and the developed countries of Europe and America[1], so future demand will lead to more consumption and carbon emissions.

Community green renewal needs the promotion of green technologies and a green lifestyle. The relevant green technologies and integration application schemes are put forward for various communities characterized by different populations and architectural features, and then promoted through residents' green lifestyles. This allows for the carbon emissions peak in cities and communities to be controlled and accelerated, so as to achieve carbon neutrality ahead of time.

Community green renewal should learn from international experience. Several European and North American cities have implemented highly successful initiatives in green development and zero-carbon community development, as well as having explored mature governance mechanisms. Reference to mature cases of international experience is an efficient path to expedite community green renewal.

Community green renewal is not only an important sector of decarbonization, but also a comprehensive topic for discussion on development. Green renewal is an important topic to advance high quality green development, including nature protection, low-carbon pathways while improving livelihoods and the quality of life of citizens. Wide participation from women is needed, and more welfare for people at all levels of society should be created. Technological innovation for community green renewal in multiple sectors needs to make the best of support from digital and AI technologies. The complexity of green renewal requires the participation of government, enterprise and the public, as well as more institutional innovation in laws, policies, technical standards, and more.

1 SITUATIONS, OPPORTUNITIES, AND DEVELOPMENT GOALS

1.1 Significance of Community Green Renewal

Community renewal and carbon emissions. Community and block renewals will become the main method for Chinese urban renewal. Communities are the main places for city life and living. From international experience, improvements in the living quality of residents will generally lead to an increase in carbon emissions per capita. The core of community renewal and renovation, however, is to improve residents' living quality. Therefore, Chinese community/life carbon emissions may rise greatly in the future unless active interventions implementing green technologies and green lifestyles are adopted. If not, community renewal is likely to become a huge drag on achieving China's "Double Carbon" goal.

The Chinese government advocates community green renovation. Since 2020, China has defined the renovation of urban old communities as significant livelihood projects and development projects[2], and put forward that by the end of the 14th Five-Year Plan, China will strive to complete the renovation of about 220,000 old, urban communities involving hundreds of millions of people, stimulating investment of up to one trillion RMB (≈154 billion USD). In July 2020, China printed and issued its *Action Plan for Establishment of Green Communities*, which advocates the idea of green development throughout the entire process of community design, construction, management, and service, and promoting environmental construction and renovation of communities by simple, moderate, green, low-carbon ways. With the gradual implementation of the Chinese urban carbon neutrality strategy, community green low-carbon renovation will gain more support from government policies and finance.

Community green renovation is a key fulcrum of urban carbon neutrality solutions. Communities present themselves as the most practical and direct application scenario for low-carbon residential energy resources. Small-scale pilots and living laboratories on the community level have been widely applied in leading cities worldwide, and have become mature test tools and means for various green technologies at the early stages of application promotion. Experience and implementaiton model of community renovation are key factors for the promotion of low-carbon technologies. They can more widely mobilize public participation and drive adoption of the green living concept, as well as contribute to the formulation of relevant policies and regulations.

1.2 Vision, Criteria and Goals of Community Green Renewal

Vision of Community Green Renewal: Achieve people's desire for a good life by green construction, management, service modes, and green lifestyles, **build** livable communities with **green prosperity, low carbon-intensive mode, circular economy, equity and inclusiveness, safety and health**, and provide "**China's samples**" for sustainable, global community renewal.

Criteria of Community Green Renewal:

Criterion 1: With the goal of meeting people's demands for a good life, green community development should advocate sustainable consumption and lifestyles, fully consider the demands of women, children, and the elderly, adequately respect the development rights of vulnerable groups, improve all people's living quality, give people the opportunity to enjoy a superior green environment and facilities, and achieve sustainable development of the life sector.

Criterion 2: Green communities should adopt green, low-carbon planning, design, and operation modes, provide high-quality public goods such as affordable housing, service, facilities, mobility, energy, water, and air quality, provide residents with good space quality to meet demands, and motivate the whole society to jointly participate in a sustainable lifestyle.

Criterion 3: Green communities should adopt effective means to circularly and efficiently utilize resources, reduce ecological vulnerability, enhance resilience and adaptation to natural and human-induced disasters and reaction capacity toward natural and man-made disasters, achieve harmony between human and nature to the maximum extent, and promote climate change mitigation and adaptation.

Criterion 4: Green technologies applied in community renewal should fully consider climatic characteristics, geographical features, development levels, development patterns, and others in different regions, and the costs should be controllable, safe, and stable. A low-carbon lifestyle, promoted in community renewal, should also have social acceptability and be easily replicated and promoted.

Criterion 5: Green communities advocate all stakeholders, according to national policies and laws, to establish and strengthen partnerships, improve coordination and cooperation, and finally facilitate community residents and even social production modes, lifestyles, and values towards the low-carbon transition, so as to achieve a common green vision.

Measures on Community Green Renewal: Based on the urgency of the “Double Carbon” goal, urban communities must adopt a “green technologies + low carbon lifestyle” intensive intervention path to achieve the green community goal.

(1) Widely Adopt Green Technologies. The green technologies, used in community renewal, should be able to reduce energy consumption and promote energy utilization efficiency, as well as reduce resource consumption and promote “circular economy.”

(2) Comprehensively Promote Green Buildings and Green Construction. Greatly increase the proportion of green buildings through the reconstruction (or retrofitting) of old buildings, and drive circular economy of resources by promotion of green building materials; promote circular economy approaches to the resuse and recycling of demolished buildings.(circular economy of building materials obtained after demolition and reconstruction).

(3) Advocate Compact, Mixed Land Utilization. Form more mixed-used public spaces, and promote intensive use of overground and underground spaces; Achieve time-share efficient utilization of more buildings through management. Promote shared building modes such as public restaurants, and build public spaces adapting to the aging and living, as well as family life and working spaces.

(4) Shape Greener, Healthier, and More Flexible Open Public Spaces. Through community renewal, expand green spaces, increase carbon sinks, and improve the microclimate; Extend community shared public space, and guide healthier and more active resident communication; Construct safer and more flexible municipal infrastructures.

(5) Achieve a Low-Carbon, Green Lifestyle. Provide residents with reliable, accessible and affordable public service, and guide residents towards green mobility; Support residents to adopt lifestyles which protect the environment and reduce resource consumption; Construct community rooftop farms, vertical gardens, and so on, and create three-dimensional micro-farms; Build vertical greening using the external facade of buildings.

(6) Encourage Market Entity and Community Residents to Participate in Community Green Renewal. Formulate supportive policies, clarify rules, and establish social conventions, and guarantee benefits for various populations, especially women, children, the elderly, and vulnerable groups. Encourage residents to directly participate in reduction of community carbon emissions, and let communities become the main outlets for citizens in fulfilling their social responsibility of reducing their carbon emission footprint.

2 DOMESTIC AND FOREIGN EXPERIENCE AND EMERGING OPTIMAL PRACTICE: FROM CITIES TO COMMUNITIES

2.1 Decarbonization Paths for Cities/Communities from an International Perspective

2.1.1 Energy

The energy transition is fundamental to getting to net-zero in China. This is not only because China's power sector accounts for around 50% of its energy-related emissions (14% of global energy-related emissions), but also because electrification will be the core of the future energy system and is vital to getting to net-zero for other sectors.

China is already the global leader in renewable energy production and has great potential in solar photovoltaic (PV) and wind power generation. If the trend of rapidly decreasing global average cost in renewable energy and energy storage continues, China could achieve 62% of electricity from non-fossil sources by 2030, higher than the 50% target set in the 14th Five- Year Plan and emissions from China's power sector could be reduced to half of 2015 levels.[3] Green hydrogen, carbon capture utilization and storage (CCUS), sustainable bioenergy and other clean energy options will be needed in sectors where electrification is not viable. Baofeng Energy Group has operationalized the world's largest solar-powered hydrogen plant in China in April this year, powered by solar PV park. According to Baofeng, the cost for green hydrogen is competitive compared with brown hydrogen (produced from coal gasification), while reducing 320,000 tons of coal consumption annually.

2.1.2 Mobility

The most important for carbon neutrality in urban mobility is the increased availability and efficiency of low-carbon transportation options. This needs planning and design of city spaces for convenient mobility. Easy walking, cycling, and an optional efficient public transportation system can significantly boost green mobility and lifestyles of the general public. Bus Rapid Transit (BRT), for instance, uses dedicated lanes to make both inter- and intra- city movement by bus quick for the public. The 15-minute community life circle, which has been widely promoted in China, uses urban design to reduce mobility volume and promote a low-carbon living mode, making all basic living needs reachable within 15 minutes walking.[4] In 'Plan Melbourne 2017-2050[5]', Melbourne is planning a 20 minutes neighborhood covering connected and walkable places where people live, work and play. 20 minutes neighborhood is all about 'living locally', with access to safe cycling and local transport options.

Additionally, technology-enabled, demand-side strategies of Transport Demand Management (TDM), shared rides and modes of mobility, and Mobility as a Service (MaaS) all create low carbon transportation incentives and solutions for consumers.[6] Autonomous Driving (AD) will also be conducive to the extension of public transport by on-demand services. The Beijing Municipal Commission of Transport and Amap signed a strategic agreement to jointly launch the Green Transportation Integrated Service Platform. This is both the first MaaS platform in China and the first with 10 million users globally. It encourages citizens to participate in green travel through carbon inclusive methods.

Another important element is the continued mass promotion of new energy vehicles (NEV), along with the construction of NEVs charging infrastructure[7] (However, the incentives for NEV is counterproductive to city planning that aims at reducing private car use in general). There are five million NEVs in China, and integration of solar power, energy storage with power batteries, fast charging, and battery swapping stations can improve the application of decarbonized energy in the transport system. Finally, alternative propulsion systems and alternative fuels, such as fuel cell EVs (FCEVs), green hydrogen production and ammonia fuels, as well as biofuels or synfuels, will be needed, especially in areas such as heavy-duty transport.

2.1.3 Building

From a full lifecycle, carbon emissions management point of view, building construction and the manufacturing of materials generate 11% of global CO2 emissions, while building operations are responsible for 28%, around half of which is from energy consumption.[8] Consequently, decarbonizing the built environment requires new buildings to be built as net-zero energy buildings (NZEB) and retrofitting existing buildings by improving the energy efficiency and electrifying building operations, and meanwhile, using renewable energy for heating as far as possible, such as industrial waste heat for district heating in northern cities. To commercialize NZEBs, green building standards are key. There are many externalities in green buildings, such as the cost for climate risk mitigation. The transformation requires these costs to be internalized and added on top of the initial capital investment and operational cost. This procedure needs to be standardized to commercialize green buildings at scale. In buildings such as Steel Structure – Modular Internal Space (SS-MIS) buildings, the materials and construction methods can be used for reducing embodied emissions, as well as improving building lifespan. Building-integrated photovoltaics (BIPV) and other forms of distributed energy storage will realize grid flexibility by digitalization and the Internet of Things. The smart operation and maintenance of buildings - Swire Properties has installed smart meters and IoT sensors into their buildings to better understand electricity, water and waste consumption as well as indoor air quality. A cloud-based smart energy management platform and a technical cloud captures all the data from across portfolios into a centralized cloud platform. The cloud platform is able to utilize 4IR technologies to monitor, analyze, and optimize their building systems.

2.1.4 Water

Water scarcity, driven by rapid urbanization and climate change, presents major challenges to industries around the world. Water management strategies and technologies can protect water resources, improve efficiency, and reduce energy and carbon emissions. Improving efficiency of Non-Revenue Water (NRW) management by reducing water leakage and promoting sewage to energy for plant self-sufficiency in wastewater treatment is an important pathway to decarbonize urban water.[9] The sponge city is a novel concept on urban flood and stormwater management and Managed Aquifer Recharge (MAR), and has been championed in China since 2015 with 30 metropolises as a part of this project.[(10,11)] The objective is to have 80% of urban areas absorb and reuse at least 70% of rainwater by 2030.[12]

2.1.5 Land-Use and Planning

The integration of technology deployment, land-use, and planning strategy is a key pillar to support cities' green transition. For example, the production of renewable energy resources will have huge implications on land use. The sponge city contributes to tackling urban artificial water bodies and green spaces and improving social wellbeing.[13] Some European cities are experimenting to reduce private car ownership and increase city space. In Brussels, Belgium, local residents can receive a local one-year public transport subscription if they sell their car without buying a new one.[14] The research in Singapore found that shared mobility could eliminate 86% of parking spaces.[15] In a similar vein, new technologies, along with the Covid-19 pandemic, have forever changed work and shopping habits, resulting in less need for office and retail space. The "ground floor" spaces open to streets and squares can be repurposed and used for meeting, co-working spaces, urban agriculture, non-profit associations, and more.[16] How these changes match with low-carbon lifestyles should be investigated in sustainable urban planning. The change in mindset that urban planning and development should be holistic, sustainable, and social is an example set by the sponge cities concept, which can be extended to future developments in response to the changes in urban spaces brought on by new, green technologies.

2.1.6 Food

Globally, the agri-food system produces a third of all GHG emissions, with China's food supply chain accounting for 11%-12%. The development of agricultural technologies, the reduction of food loss and waste, and the shift of dietary patterns are of importance to reducing GHG emissions from the agri-food system and realize carbon neutrality.[17] Agricultural technologies may directly reduce GHG emissions, as well as indirectly through increased productivity, better supply chain linkages, and more. The majority of food-related emissions come mainly from farmland emissions, animal enteric fermentation, rice cultivation, manure management, and agriculture residuals.[18]

The principal factor in GHG emissions, water consumption, and land-use area pressure in the agri-food system is the growth of meat consumption in China.[19] Reducing food waste, shifting away from meat consumption, and deploying city-relevant agricultural technologies are very important to achieve the carbon neutrality goal. Vertical farming, as an emerging technology, is characterized by high crop yield, low water utilization, and efficient utilization of natural resources. The majority of vertical farming in North America currently focuses on high-value crops, but its use in China is limited due to its relatively high cost.

2.2 Experience on Green Renovation Technologies in Domestic and Foreign Communities

With Sweden Hammarby Sjstad, Malmo Seashore Eco-City, and Royal Seaport City as the main cases, combined with Tokyo Boye New City, Copenhagen, Singapore, and Shanghai Meilongsan Village low-carbon demonstration community, the research focuses on experiences gained in green technology promotion, lifestyle initiatives, convention guarantees, policy support, etc.

2.2.1 Green Technologies

The application of green technologies has gradually evolved from a single technology to multi-dimension integration. For example, Hammarby and Royal Seaport City proposed the "SymbioCity" idea, including urban spaces, mobility, energy, water, solid waste, green buildings, intelligent management, and environmental greening, for a total of 42 green technologies in seven dimensions. In accordance with the relevance between technologies and external systems as well as local applicability, the research classified the 42 technologies into three categories:

Green technologies supported by external systems. This category of green technologies needs to be carried out on a larger scope, or needs ancillary facilities from municipal administration, including consensus of relatively mature compact blocks, mixing functions, public transport, etc., to reduce carbon emissions by nearby accessibility or low-carbon travel for the goals of employment, residence, and leisure. The other nine technologies can be summarized as two trends: The first one is municipal infrastructure towards distributed transition. The average energy utilization rate of traditional vertical electric system is about 36%, while the distributed energy systems usually use multi-variant energy supply methods such as gas turbine, solar energy, biomass energy, fuel cells, combined heat and power generation, and combined cold, heat and power (CCHP), with a comprehensive energy utilization efficacy of up to 70-90%. The second one is the transition of energy, water, and solid waste systems from independent operation to cross-net collaboration and circular symbiosis, including waste water being made into biogas, and bio-compost, but this needs to be arranged in a larger scope. In Hammarby, for instance, 50% of energy comes from solar energy, and the other 50% is from power generation by garbage, biogas, and waste heat.

Green technologies in newly built areas. This category of green technologies usually has higher requirements for ancillary facilities and applies to newly built areas. These technologies include district cooling, underground vacuum refuse collection system, green building materials, passive buildings, and flexible power distribution. At present, there are two green technologies which have been widely used in foreign cases and gradually tried in China. The first one is district cooling technology, which uses off-peak electricity for refrigeration and accumulation of cold in the nighttime and provides regional central cooling in the daytime. It is applicable to regions with high-density demand for cooling capacity. The other one is the underground vacuum refuse collection system. There are approximately a thousand cases with successful operations at present, but no successful practical case due to insufficient garbage classification and management system problems at home and abroad.

Updated green technologies in blocks. This category of green technologies is mainly used for small facilities or intellectualized systems and applicable to renewal and renovation of block greenization. Among these technologies, photovoltaic technology, green roofs, reuse of reclaimed water, and most green building technologies have been gradually promoted in China. These technologies represent three big trends: The first one is that energy supply side, storage side, and client side have increasingly intense demands for direct current (DC), and thus the DC micro-grid gradually becomes an important development direction of the electric power system. A neighborhood with 300m*300m DC micro-grid can be established in accordance with the optimal transmission distance of DC. The DC power supply system can be built by relying on distributed generation and stored energy facilities to enable each user of the electric energy to become a provider of clean electric power. The second one is to use heat pump technology to recycle waste heat, make cascade heat (cold) supply, and enhance energy efficacy. Nordic countries such as Sweden pay much attention to recoveries of indoor waste gas, exhaust gas in traffic yards and stations, waste water, and waste heat produced in the incineration-power generation to form sewage source heat pump, air source heat pump, ground source heat pump, and so on. The heat pump technology is carried out in China now. The third one is the transition of the technological means from physical facility optimization to virtual operation optimization, and smart micro-grid and virtual power plant are the two commonly-used technologies. The smart micro-grid can form independent community self-circulation when local generating capacity is adequate; it can store electricity or sell grid-connected electricity when local generating capacity is excessive; it can be supplemented by urban power grid when it is insufficient. The virtual power plant can organically combine distributed generator set, controllable burden and distributed stored energy facilities, and achieve integration and control by the control technology and the communication technology so as to be a special power plant to participate in the electricity market and power grid operation. Mature solutions for virtual power plants have not been formed yet due to the problems of the electricity system in China.

2.2.2 Green Lifestyle

The developed countries and green and environmental protection organizations publicize green lifestyle continuously and widely. For example, *Sustainable Living Guide*, issued by World Wide Fund For Nature, includes five aspects, i.e., clothing, food, housing, transportation, and leisure, and advocates choosing environmentally-friendly fabrics, giving used clothing to others, eating at home, not wasting when ordering food, choosing and using energy-saving appliances, garbage classification and decrement, bike sharing, low carbon cars, enjoying nature, not wasting disposable daily necessities, and other specific details of life. Through continuous decades of developed economic models, the Union of Concerned Scientists (UCS) have obtained a real carbon emissions image of the U.S., and teased out ten ideas for the lowest-carbon life, including using hybrid electric vehicles, eating 50% less meat not drinking bottled beverages, reducing 20% of shopping, and so on. *Curbed*, a US website, also issued *101 Actions to Tackle Climate Change*, which tells how to achieve low carbon life at home, on the road, and in communities.

More and more inhabitants begin to accept and practice green lifestyles in many cities and communities of Europe and North America. Particularly in zero-carbon communities and the cities that have a carbon neutrality goal, such as Hammarby and Copenhagen, green consumption and lifestyle have been widely accepted, which lays the social and public opinion foundation for them to achieve the goal of carbon neutrality.

2.2.3 Convention Guarantee

There are government or community conventions to constrain carbon emission-generating behaviors in green communities of developed countries. For example, in Hammarby, the government requires all residents to sign an environmental protection contract before residence, promise joint efforts to achieve the goals of saving electricity and water, and strictly execute garbage hierarchical classification and "pay-as-you-throw." The government also organizes a car-sharing group, provides environmentally-friendly goods which can be obtained at any time and include organic dustbins, biodegradable garbage bags, energy-saving bulbs, and so on. Vauban Community (Germany) devotes itself to building an ideal community which shares a common fate with residents. Citizens are allowed to participate in the decision-making process and have discussed the idea of a car-free community and a "Zero-Tolerance Parking Policy." The community has achieved a car ownership rate at only 174 vehicles per thousand people, which is far lower than the nationwide average of 504 vehicles per thousand people in Germany.

Strengthening low-carbon consciousness of the public is an important guarantee to propel implementation of the community convention, done by providing information, consultation, training, etc. Copenhagen lists the cultivation of "Climate Citizens" as an important part of the Lighthouse Plan. The UK executes the "Green Home Plan" and provides family energy-saving consultation for London residents. In China, the creation of a national low- carbon day has become an important information window to publicize a green, low-carbon social climate.

2.2.4 Policy Support

Economic means are the most commonly used international means. The economic incentive policies include tax revenue, subsidy, and price policies. Hammarby stipulates that developers and contractors can obtain government subsidies if they pass the evaluation of ELP. In the initial period of construction, the government promised a subsidy of about 22 million Euros for the extra cost of autonomous environmental protection measures and technologies (the subsidy for the construction cost of the vacuum refuse collection system is up to 50%). During construction, the government constrains developers through the contract on development of urban construction, and requires the construction to meet the basic requirements and the goal of energy efficiency solutions.

Administrative means are the uppermost means in China. Through a series of policies and regulations, the government should clarify the standards and construction requirements of the energy-saving products, such as requiring building enterprises to publish energy consumption and emission standards, as well as whether equipment and materials are energy-saving, environmentally-friendly, etc. Carbon emission is listed as one of factors for government tender. Royal Seaport City put forward that the sustainable requirement should be listed in the land development conditions, included in early planning, and become an influence factor to win the bidding. The specific environmental protection conditions for developers include the energy consumption level per unit area, standards of wind or solar heat collection, water consumption, environmentally-friendly building materials, garbage collection vacuum piping system, environment management system, and so on. For the design of public areas, the construction also adds the use of light-color coatings in squares and streets, prioritization of slow-down and public traffic systems, and the setting of car-sharing spaces.

3 Characteristics of Carbon Emission in Cities and Communities: Empirical Analysis of Five Cases

3.1 Selection of Cities and Communities as Cases

The factors for selection of communities include the following aspects: The first one is the technological level of community construction at different times. The construction times of these communities are from 1980s to 2010s, reflecting characteristics and problems of community construction in different stages. The second one is different crowds and inhabitation forms. There are middle-income communities, low-income communities, tenement communities with young people as the majority, standard communities with core families as the majority, and aging communities with urban original residents as the majority. There are different kinds of commercial housing communities, communities with private property rights, and high-density housing communities with rural collective property rights. The third one is different climatic regions and different scales of cities. These cities include: megacities, super-cities, small cities; plains, mountainous and hilly cities; hot cities in the south and hot-summer/cold-winter cities. Furthermore, factors such as community location and green technologies were also considered.

The five communities from the four cities selected as the research subjects comprise of: Shanghai Shi Bo Jia Yuan Community, Jing Jiang Yuan Community, Chongqing Hongyupo Community, Shenzhen Heyi Community, and Jiangshan Dongtang Community.

3.2 Basic Information on the Communities and Socio-Economic Characteristics of the Population

3.2.1 Basic Information on the Communities

Both Shi Bo Jia Yuan Community and Jing Jiang Yuan Community are located in Pujin Street, Minhang District, Shanghai, 15 km away from the central city (People's Square), nearby Rail Traffic Line 8 directly towards the central city. There is a AAA hospital, middle and primary schools, a hypermarket, a church, and other public service facilities within 500m. The communities have thorough community-level public service facilities and preferable greening levels, and the infrastructure, such as waterproofing for external walls, public lighting, and garbage classification, have been renovated and transformed through the “Beautiful Homeland Transformation” project. Moreover, Shi Bo Jia Yuan Community uses heat insulation walls and double-glazing green technologies.

Hongyupo Community is located in Jiulongpo District, Chongqing. Shiqiaopu region is one of the traditional centers for trade of the main urban area, with high-density population, convenient traffic, and hilly and mountainous topography. The overall quality of the buildings is poor, and roof leakage, wall cracking, stained and damaged wall space, and other problems are present. The public environment of the community needs improvement. There are serious problems in water resources, pollution discharge, dustbin cleaning, and coordination of property management companies, and it is very difficult to maintain public facilities.

Heyi Community is located in Baoan District, Shenzhen, and almost entirely surrounded by industrial parks, including manufacturing enterprises of electronic information parts. It is a newly-built multilayer urban village with very high building density and without public space. Commerce at the bottom of the residence is the main service space and provides drinking water stations, restaurants, community shops, and internet bar services for tenants.

Dongtang Community is located in the core of the old urban area of Jiangshan. Its residents can go to the core of the old urban area only by walking. There is commerce along the street, the Jiangshan Library, the Popular Science Activity Center, and other city-level public service facilities within 500m. The land property rights of the community belongs to the residents, and are mostly either single placement dwellings with one to three floors, houses built on the funds collected by the buyers, or self-built houses. These houses are simple and crude, but heat preservation and ventilation are good. No explicit public spaces and public service facilities exist, including a lack of street lamps in the community. Some residents' water supply and fuel gas are not connected to the municipal pipe.

	Shi Bo Jia Yuan Community	Jing Jiang Yuan Community	Hongyupo Community	Heyi Community	Dongtang Community
Location	Pujiang Town, Minhang District, Shanghai	Pujiang Town, Minhang District, Shanghai	Jiulongpo District, Chongqing	Shajing Street, Baoan District, Shenzhen	Core of the old urban area of Jiangshan
Construction Age	2006	2004	1970~1980s	2010	1990s
Characteristics	New community with low carbon technology	New community without low carbon technology	Aging community	Rental houses in the urban village	Aging private property right
Site Area	29ha	18ha	40ha	8.1ha	5.3ha
Plot Ratio	1.28	1.24	1.34	2.19	0.88
Building Floors	Many multistory buildings, and few medium height	Multistory buildings	Many medium height buildings and few multistory	Many medium height buildings	Many medium height buildings

	buildings		buildings		
Building Quality	Good	Good	Poor	Good	Poor
Green Area	90364	66744	132671	0	0
Renewable Building Area	0	0	107025	0	46800

Fig. 3-1 General chart of basic information of the five communities

3.2.2 Socio-Economic Situation

Shi Bo Jia Yuan Community and Jing Jiang Yuan Community are middle-income communities with the core families as the majority. Jing Jiang Yuan Community consists of placement dwellings due to local removal and relocation. The education and income levels are lower than Shi Bo Jia Yuan Community, but the age structure is relatively young. Hongyupo Community is an aging community with stem families as the majority, and the income of residents is low. The proportion of rentals is high, and most renters are migrant workers and college graduates. The low rental price and convenient commuting options are the core advantages for attracting renters. All houses of Heyi Community are rental houses for staff working near industrial parks. Renters are mostly single, relatively young, and their education at the level of junior-senior high school. Dongtang Community is a community with small urban private property rights and with core families as the majority. It is not an aging community; both the income and the education level are the lowest among the five communities.

Fig. 3-2 General list of basic information of the five communities

Community Name	Shanghai-Shi Bo Jia Yuan Community	Shanghai-Jing Jiang Yuan Community	Chongqing-Hongyupo Community	Shenzhen-Heyi Communit y	Jiangshan-Dongtang Community
Total number of people	10119	6268	16000	11891	1734
Number of households	4195	2420	5383	8252	789
Average number per household	2.41	2.59	3.0	1.4	2.2
Family structure	Core families	Core families	Stem families	Single or double lessees	Core families
Aging ratio (60 years old or above)	35%	22%	60%	1%	13%
Rental rate	20%	29%	60%	98%	0%
Income level	Upper middle	Middle	Middle	Relatively low	Relatively low

3.3 Data Collection, Measurement, and Analysis of Carbon Emission in the Communities

3.3.1 Data Collection in the Communities

To measure carbon emissions in these communities, four kinds of data were collected, i.e., domestic energy consumption data, resident mobility data, the clothing, food, and living data, and green carbon sequestration data. This research obtained the data mainly through communities and property management companies.

Household energy consumption data was collected in terms of the use of electricity, water, and fuel gas in the peak months, and the annual accounting was done in accordance with the ratio of the peak months to the whole year. It was not convenient to enter houses to collect the residents' mobility data due to the Covid-19 pandemic, so the data was calculated by mobile phone signaling and then checked through urban mobility survey reports. The clothing, food, and living data were measured in line with the amounts of garbage collection, water supply, and urban residents' food consumption. The green carbon sequestration data was obtained in accordance with the plane graphs of communities.

3.3.2 Metering Method of Carbon

Based on the relative research on measurement of carbon emissions, it was concluded that carbon emissions in blocks mainly involved community energy consumption, resident mobility, food, clothing, and life, and green carbon sequestration. The specific computational formula for the total carbon emissions in blocks is: E=Ee+Em+El-Eg. E refers to the total carbon emissions in blocks; Ee means the total carbon emissions from community energy consumption; Em refers to the total carbon emissions from resident mobility; El means the total carbon emissions from food, clothing, and life; Eg means the total green carbon sequestration.

3.4 Structure of Carbon Emission and Analysis of Influence Factors in These Communities

3.4.1 Structure of Carbon Emission in the Five Communities

In terms of of total carbon emissions, the characteristic of high carbon emissions is obvious in the two communities of Shanghai, with the carbon emissions per capita up to 2.2~2.3t each year, about two times that of the other communities; the carbon consumption per capita is low (about 1t each year) in the two communities of Shenzhen and Jiangshan; it is moderate (1.6t each year) in the community of Chongqing.

In terms of the structure of carbon emissions, there is a large difference among different cities, and the carbon emissions from resident energy consumption and mobility accounts for the main proportion. The energy consumption of the Shanghai communities is the highest, and the carbon emission is up to 1~1.2t each year, accounting for about half of total carbon emissions; because of long-distance commuting, the carbon emissions from mobility is also high - up to 0.6t each year, accounting for 30% of total carbon emissions. The energy consumption of the Shenzhen and Jiangshan communities is only 1/3~1/4 that of the Shanghai communities, and the carbon emissions from mobility are also very low. The Chongqing community is located in a central urban area. Meanwhile, the degree of aging is relatively high; the carbon emission from energy consumption and mobility is about a half that of the Shanghai communities. There is no large difference in the total carbon emissions from life per capita, with an average of about 0.5~0.6t in each community. The contribution of carbon sequestration is slightly different due to community greening differences, but in whole, the proportion is not high (about 3%).

Table 3-1 Comparison of total carbon emissions per capita and structure among the five communities (Unit: t/person • year)

		Shanghai-Shi Bo Jia Yuan Community		Shanghai-Jing Jiang Yuan Community		Shenzhen-Heyi Community		Jiangshan-Dongtang Community		Chongqing-Hongyupo Community	
Situation of carbon emissions		Per capita	Proportion	Per capita	Proportion	Per capita	Proportion	Per capita	Proportion	Per capita	Proportion
Resident energy consumption	Water	0.02	0.80%	0.02	1.00%	0.01	0.70%	0.01	0.80%	0.04	2.20%
	Electricity	0.94	43.00%	1.01	43.40%	0.31	27.90%	0.27	28.60%	0.34	20.30%
	Gas	0.12	5.60%	0.18	7.70%	0	0.00%	0	0.00%	0.26	15.60%
	Total	1.08	49.30%	1.21	52.10%	0.32	28.60%	0.28	29.40%	0.63	38.10%
Mobility	Total	0.64	29.20%	0.64	27.60%	0.19	16.90%	0.02	2.20%	0.32	19.30%
Municipal administration	Solid waste	0.17	7.50%	0.17	7.20%	0.23	20.50%	0.28	29.30%	0.26	15.70%
	Waste water	0.04	1.80%	0.05	2.10%	0.01	1.30%	0.02	1.80%	0.19	11.20%

	Total	0.21	9.30%	0.22	9.30%	0.24	21.80%	0.3	31.10%	0.45	26.90%
Life	Breath	0.08	3.50%	0.08	3.30%	0.08	6.90%	0.08	8.10%	0.08	4.60%
	Food	0.26	11.90%	0.26	11.30%	0.28	25.80%	0.28	29.20%	0.24	14.50%
	Total	0.34	15.40%	0.34	14.60%	0.36	32.70%	0.36	37.30%	0.32	19.10%
Carbon sequestration	Plant	-0.07	-3.20%	-0.08	-3.60%	0	0.00%	0	0.00%	-0.06	-3.40%
Total carbon emission		2.2	100%	2.32	100%	1.11	100%	0.95	100%	1.66	100%

In terms of carbon emissions per unit area, it is the highest in Shenzhen Heyi Community, and up to 104g per square meter. The living space per capita of Heyi Community is low and the carbon emissions per capita is not high, but the carbon emission per unit area is close to two times of that in a normal community. The carbon emissions per unit area is similar and about 60kg each year in the Shanghai communities and the Chongqing community. In Jiangshan community, the living standard is low and the infrastructure not perfect, and thus the carbon emissions per unit area is the lowest and about 35kg each year.

Table 3-2 Comparison of total carbon emissions per unit area and structure among the five communities (Unit: kg/m2 • year)

		Shanghai-Shi Bo Jia Yuan Community		Shanghai-Jing Jiang Yuan Community		Shenzhen-Heyi Community		Jiangshan-Dongtang Community		Chongqing-Hongyupo Community	
Situation of carbon emissions		Carbon emissions per unit area	Proportion	Carbon emissions per unit area	Proportion	Carbon emissions per unit area	Proportion	Carbon emissions per unit area	Proportion	Carbon emissions per unit area	Proportion
Resident energy consumption	Water	0.47	0.80%	0.63	1.00%	0.69	0.70%	0.3	0.80%	1.51	2.20%
	Electricity	25.21	43.00%	28.12	43.40%	29.14	27.90%	10.05	28.60%	13.72	20.30%
	Gas	3.27	5.60%	4.98	7.70%	0	0.00%	0	0.00%	10.53	15.60%
	Total	28.95	49.30%	33.73	52.10%	29.83	28.60%	10.34	29.40%	25.76	38.10%

Mobility	Total	17.13	29.20%	17.9	27.60%	17.69	16.90%	0.76	2.20%	13.03	19.30%
Municipal administration	Solid waste	4.41	7.50%	4.65	7.20%	21.39	20.50%	10.32	29.30%	10.61	15.70%
	Waste water	1.04	1.80%	1.38	2.10%	1.38	1.30%	0.65	1.80%	7.59	11.20%
	Total	5.45	9.30%	6.03	9.30%	22.77	21.80%	10.97	31.10%	18.2	26.90%
Life	Breath	2.03	3.50%	2.14	3.30%	7.24	6.90%	2.84	8.10%	3.1	4.60%
	Food	7	11.90%	7.32	11.30%	26.92	25.80%	10.25	29.20%	9.79	14.50%
	Total	9.03	15.40%	9.46	14.60%	34.16	32.70%	13.09	37.30%	12.89	19.10%
Carbon sequestration	Plant	-1.89	-3.20%	-2.35	-3.60%	0	0.00%	0	0.00%	-2.33	-3.40%
Total carbon emission		58.68	100%	64.76	100%	104.46	100%	35.16	100%	67.55	100%

3.4.2 Analysis of Factors Influencing Carbon Emissions

It can be seen from the comparison of the five communities that the main factors influencing carbon emissions in communities include residents' living standards, residential morphology, community types, mobility characteristics, energy consumption behaviors, etc.

First, the higher the residents' living standards, the higher the carbon emissions. From the macro perspective, the carbon emissions of residents have a positive correlation with GDP, and the communities also follow this rule. A higher income level directly leads to an increase of carbon emissions from residents' life energy consumption and mobility[20]. In the communities with a high income level, the living space per capita is relatively high, the residents use more kinds of domestic appliances and in higher frequencies, and the car ownership rate and motorization level are also high; all of these can cause an increase in carbon emissions. It can be seen from the cases that although Shi Bo Jia Yuan Community has used the green energy-saving technology, the carbon emissions per capita is still high.

Second, the higher the degree of mixed functions near communities, the lower the carbon emissions. A high degree of mixed functions, especially in regards to the job-housing balance, can greatly reduce the carbon emissions of residents from mobility, thereby affecting total carbon emissions. The carbon emissions from mobility are relatively low in Hongyupo Community and Dongtang Community, both of which are located in the central urban area. Heyi Community is located in an industrial agglomeration area, and the lessees are employees of the enterprises and can walk to their jobs; as a result, the carbon emissions from mobility are very low. Hongyupo Community is located in the central urban area, with the railway and public transportation being quite convenient, and private car ownership rate very low; therefore, the carbon emissions from mobility are also relatively low. On the contrary, the two communities of Shanghai are located in suburbs and there is little employment nearby, so the commute time and distance of residents are far higher than those in other communities; as a result, the carbon emissions from mobility are high and close to 30%. Therefore, better job-housing balance can greatly decrease the total carbon emissions in communities.

Third, the residential morphology decides the carbon emissions per unit area. Jing Jiang Yuan Community, Shi Bo Jia Yuan Community, and Hongyupo Community are conventional commodity housing communities with family housing as the majority. Although the intensity of energy consumption and the mobility distance are different, the carbon emissions per unit area are at the same level. On the other hand, in Dongtang Community, as privately-owned housing, the level of pipe network construction is relatively low, and residents tend to use natural water sources and natural ventilation; as a result, the carbon emissions per unit area is only a half of that in conventional communities. Of course, the influences of residential morphology on carbon emissions are comprehensive, including difference of population structures, land use mixedness, etc.

Fourth, daily behaviors have great influence on carbon emissions. In Hongyupo Community, the aging community is quite frugal in their energy consumption, and thus carbon emissions per capita is relatively low. In Shenzhen Heyi Community with a high lease rate, residents go out early, come home late and do not cook and eat at home. Thus, the building energy consumption is also relatively low. Even within the same community, such as Shi Bo Jia Yuan Community, the families with elder population have strong energy-saving consciousness and economical living habits, and thus the domestic energy consumption is also lower than ordinary families and can be reduced by up to 15%.

Fifth, energy-saving technologies indeed reduce carbon emissions, but also increases continuous costs. Generally, the building energy consumption per capita is lower in the low- carbon communities with application of green technologies than in ordinary communities. For instance, the energy consumption per capita is lower in Shi

Bo Jia Yuan Community than in Jing Jiang Yuan Community, both of which are in the same location and have similar population structures. However, it was found in the investigation that because the low-carbon technology is not yet mature, high, subsequent maintenance costs have occurred; wall space and roofs need to be repaired each year, which causes an inconvenience to the residents' lives. Therefore, the degree of maturity of green technologies and the subsequent maintenance cost should also be considered when choosing technology.

Also to consider, the influence of the material space of communities on carbon emissions may include: Building height has a certain impact on carbon emissions in communities; the physical planning elements such as residential design and building design have impact on microenvironment of communities, thereby indirectly affecting carbon emissions; larger families can have higher total carbon emissions, but help reduce carbon emissions per capita.

4. Outlook for Future Carbon Emissions in Urban Communities and Decarbonization Challenges

As urban communities in China continue to develop rapidly, their energy consumption and carbon emissions are bound to increase. Meanwhile, community renewal will result in a significant amount of extra carbon emissions. Without green technology or green renewal methods, urban renewal will prove to be a major obstacle to achieving China's goals of carbon neutrality and emissions peaking.

4.1 Future Needs and Trends of Urban Communities

The future needs of China's urban communities mainly come from four areas, namely residential energy use, mobility, utilities, and daily living.

4.1.1 Trends in Residential Energy Use

It is clear that China's residential energy consumption continues to grow**, and a large increase in demand is expected in the future.** According to the China Building Energy Consumption Research Report (2020), energy consumption of residential buildings in most cities increased more than twice in 2020, and building energy consumption in most regions grows at an average rate of six to ten percent per annum. China's per capita household energy consumption was 415.6kgce in 2017, which was slightly above the world average, or equivalent to 82% of that of Japan, 54% of the EU, and 39% of the US. Statistics show that, as per capita GDP grew from USD 17,000 to 25,000 in the United States, and from USD 10,000 to 20,000 in the EU and Japan, energy consumption jumped up. China is currently at the same stage of growth. Relevant studies reveal that, without human intervention, the total energy consumption of urban residential buildings in China will peak in 2045-2050, and is expected to increase from 361 million tce in 2017 to 510 (±52) million tce[21], with an incremental demand of more than 40%.

The main types of residential energy use in the case communities are electricity and natural gas. Residential electricity consumption includes lighting, hot water, home appliances, heating, and cooling. Lighting energy use is not expected to increase significantly; hot water will consume a growing amount of energy, especially in Dongtang and Heyi; energy consumption of home appliances will grow significantly, especially for kitchen appliances in the Shanghai and Chongqing communities and for smart electronic products in Shenzhen communities; communities in the hot-summer/cold-winter zone, such as Shanghai, Chongqing and Jiangshan, will have a huge growing demand for heating, and will use air-conditioning for cooling more frequently and much longer. Therefore, residential electricity demand in the case communities is on the rise and expected to peak by around 2035.

Table 4-1 Analysis of Residential Electricity Demand in Case Communities and Their Cities (t/y)

Name of community	**Jingjiangyuan, Shanghai**	**Shibo Jiayuan, Shanghai**	**Hongyupo, Chongqing**	**Heyi, Shenzhen**	**Dongtang, Jiangshan**
Per capita residential electricity consumption of case communities in 2020 (kWh/y)	1700	1601	590	743	525
Projected per capita residential electricity consumption in the city in 2035 (kWh/y)	1940		1352	1417	1289
Projected per capita residential electricity consumption of case communities in 2035 (kWh/y)	2300	2150	1100	1290	1300
Projected electricity consumption per unit of residential floor area of case	61	60	45	87	48

communities in 2035 (kWh/y m²)					
Key drivers of higher energy use in the future	Heating, home appliances		Heating, cooling, home appliances	Hot water, home appliances	Home appliances, heating, hot water

Natural gas is mainly used for cooking and hot water. It is expected that the demand for natural gas will remain stable in the Shibo Jiayuan, Jingjiangyuan and Hongyupo communities without external intervention. Heyi community is a rental community, and the demand for cooking gas is limited. Therefore, natural gas use is not considered in this case for the future. Dongtang community will have a certain increase in demand after connecting to the natural gas network.

After converting the forecast results of each community into energy consumption, the residential energy demand curve is formed as follows. On the whole, residential energy consumption of communities will increase significantly. Depending on the climate zone, per capita living area and development level of each community, the increase in per capita residential energy consumption and the time to peak will differ. In 2035, energy use will increase by 20% in Shibo Jiayuan and Jingjiangyuan, 37% in Hongyupo, 77% in Dongtang and 42% in Heyi.

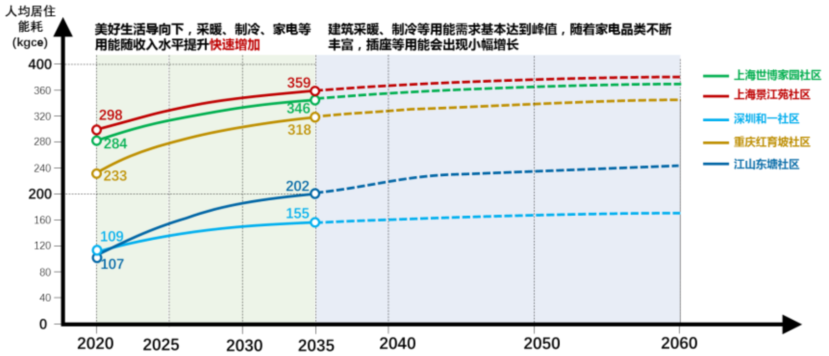


Figure 4-1 Residential Energy Consumption and Demand Curve of Case Communities (without intervention)

4.1.2 Mobility Energy Consumption Trends

In 2020, car ownership in China was 260 million, and the number of motor vehicles per 1,000 people was over 180, which was far behind that of developed countries. As the economy continues to grow, demand for motorized private transport will increase in the future if not regulated by policies and guidance from the state, municipalities and communities.

Table 4-2 Comparison and Share of Three Typical Models of Mobility

Model	Public transport (%)	Motorized private transport (%)	Non-motorized transport (%)
North America	<10	>50	10~20
Europe	30~40	30~40	30
Asia	>50	<20	20~30

Source: LU Ximing, Urban Transport in Asia, Tongji University Press, May 2009

Case communities had 10% to 20% of motorized private transport in 2020, with per capita annual energy consumption of at least 26kgce in Dongtang and at most 83kgce in Shibo Jiayuan. Without green intervention, the share of motorized private transport will continue to rise in the future, whereas public and non-motorized transport will decline, leading to a significant increase in energy consumption and ultimately developing into a structure similar to the European model. Due to the different population sizes, travel distances, locations, income levels, and housing patterns, energy consumption in the mobility sector will differ greatly among the communities in 2035. The two communities in Shanghai may have 45% motorized private transport, while Heyi, Hongyupo and Dongtang may only have 30%. The per capita annual traffic energy consumption is highest in Shanghai Shibo Jiayuan at 182kgce, and lowest in Jiangshan Dongtang Community at 49kgce, which is rather similar to peer communities in European countries.

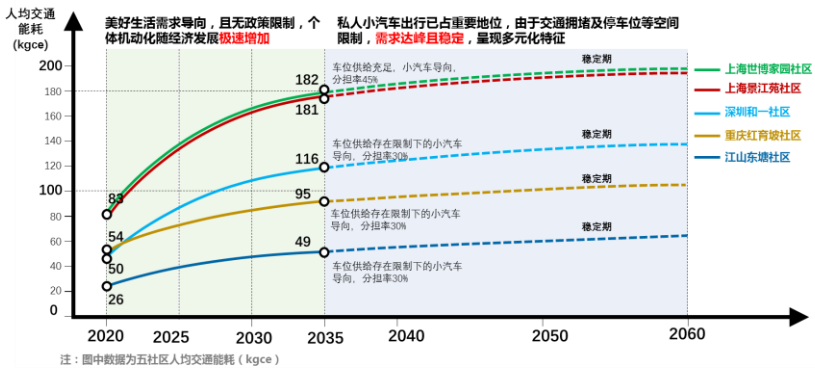


Figure 4-2 Mobility Energy Consumption and Demand Curve of Case Communities (without intervention)

4.1.3 Carbon Emissions Trends in the Municipal Sector

Water consumption and solid waste of the five case communities will be the main sources of carbon emissions in the municipal sector. With improving living standards and changing habits in the future, per capita daily domestic water consumption and waste generation in case communities will maintain an upward trend as average income and housing area grow, without considering policy regulation and green technology promotion. Community-generated municipal carbon emissions are expected to increase considerably, based on future trends in urban water use, total waste generation and corresponding carbon emissions data. There are now wide disparities between communities, which will rapidly narrow and converge. Reductions achieved through green behaviors are unlikely to fully offset the incremental carbon emissions from improved quality of life.

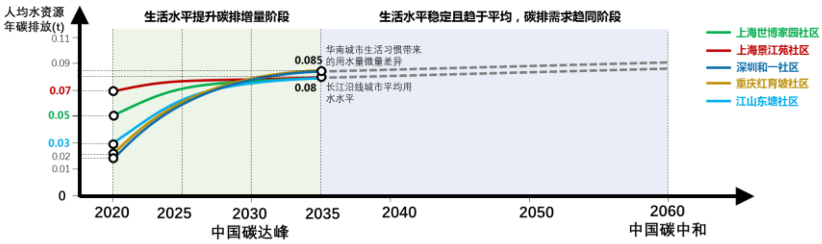


Figure 4-3 Municipal Carbon Emissions Trend Curve of Case Communities (without intervention)

4.1.4 Trends of Carbon Emissions Related to Daily Living

Carbon emissions related to daily living mainly refer to food consumption. As urban dietary patterns in China shift toward higher carbon intensity, per capita carbon emissions from food consumption will increase significantly, so will the share of emissions from food in the domestic carbon emissions of residents. In 2016, plant-based food accounted for 81.40% of total per capita food consumption in China. Vegetarian food still occupies an important place in the daily diet of Chinese residents, and emissions from this area remains relatively low[22]. With the increasing consumption of animal proteins and fats such as dairy and meat, food consumption structure gradually shifts from plant-based to animal-based. The average per capita carbon emissions from food consumption in China grew at 1.68% per annum from 1997 to 2016[23]. Based on this, case communities are tentatively expected to generate at least 0.31t per capita per annum by 2035.

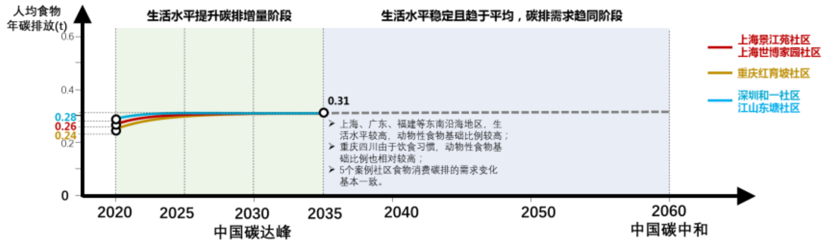


Figure 4-4 Carbon Emissions Trend Curve of Daily Living in Case Communities (without intervention)

4.2 Building Retrofitting Methods and Their Impacts on Carbon Emissions and Energy Consumption in Case Communities

Three of the five case communities will undergo building retrofits of varying scales before 2060. From the perspective of building life cycle analysis, construction and demolition of buildings can produce a high amount of carbon emissions. Therefore, it is important to analyze and assess potential carbon emissions of building retrofits for community renewal.

4.2.1 Carbon Accounting Method for Renewal and Retrofit Projects

Accounting parameters for carbon emissions of building retrofits is determined in accordance with the Standard for Building Carbon Emission Calculation GB/T51366-2019, and with consideration of the actual demand and data availability.

Carbon emissions from new construction. The calculation includes carbon emissions from production and transportation of building materials as well as construction. Based on relevant studies[24,25,26], carbon emissions of new residential buildings are taken to be 0.6t CO^2/m^2 under the conservatism principle.

Carbon emissions from building demolition. The calculation includes emissions from demolition and waste disposal. According to relevant studies[27,28], the value is set at 0.05t CO_2/m^2.

Carbon emissions from green retrofit. The calculation includes emissions from energy efficiency retrofits of building envelopes, energy-efficient equipment replacements, indoor environment improvement and interior decoration and furnishing. It also concerns the production of building materials and transportation as well as construction. Greening retrofit can improve the quality of living environments and promote energy efficiency. According to several related studies[29][30], the value of 0.24t CO_2/m^2 is taken as the estimate of carbon emissions from green retrofit, which are 40% of the emissions from new construction.

Carbon emissions from structural reinforcement projects. The calculation includes emissions from production and transportation of building materials as well as construction. YANG Shichun's[31] research shows that the average age of a building designed and constructed with 50-year service life is 88.5 years, and it takes an average of 150 years before the building's load bearing capacity fails due to performance degradation. Emissions from extending building service life by 20 years is calculated at 0.145t CO_2/m^2, or 25% of the energy consumption for new construction. The case communities of this project were built between the 1970s and 2010s, hence no need for comprehensive reinforcement until 2060. This study assumes that 20% of the building stock will be reinforced, and estimates the schedule of such reinforcement on the basis of building conditions and the need for renewal of each community. Carbon emissions of reinforcement are accounted at 25% of that of new construction, which is at 0.15t CO_2/m^2.

Table 4-3 Estimated Carbon Emissions Value for Building Renewal and Retrofit

Stage of development	Carbon emissions per unit of residential building area (tCO_2/m^2)
New build (production and transportation of building materials + construction)	0.6
Demolition (demolition + waste disposal)	0.05
Green retrofit	0.24
Structural reinforcement	0.15

4.2.2 Timing, Method and Content of Renewal and Retrofit in Case Communities

The schedule for renewal and retrofit projects is mainly under the influence of communities' demand for quality improvement and government planning. Hongyupo is an old community compound whereas Heyi has mostly $15m^2$ single-room apartments in high-density buildings. Both have a strong demand for quality improvement, and are included in the government's recent retrofit plan for old communities. The retrofitting work is set to start before 2025. Dongtang Community has poor building quality and a strong desire for quality improvement. However, its housing units are all privately owned, so they have not been included in the government's retrofit plan yet. Retrofitting may start after 2025. Shanghai Shibo Jiayuan and Jingjiangyuan were built relatively recently with good building quality, so there is no need for retrofitting before 2060.

The retrofit method is mainly influenced by government plans and building ownership. Hongyupo community offers commercial property, and has been included in the government's retrofit plan. It is likely that the government will organize the retrofitting work in due course, with limited amount of demolition and construction over a period of 4-5 years. Heyi community has farm houses built on collectively owned construction land, and has been included in the government's retrofit plan. The houses may be collectively retrofitted under village organization over the course of 4-5 years. Jiangshan Dongtang community has private property houses, and is not included in the government's retrofit plan. An overall retrofit is unlikely to happen. It is assumed that residents will spontaneously make retrofit works from 2026 over a period of 10 years.

The renewal and retrofit work of each community varies greatly. Hongyupo community has relatively new high-rise buildings which do not require retrofitting. The three dilapidated buildings as well as old buildings with less than four stories will be demolished and rebuilt based on the actual situation; six-story buildings will undergo green retrofit and about 20% of them with poor quality will be structurally reinforced. Heyi community has multi-story buildings which all require retrofitting. A small number of buildings will be demolished. Dongtang community has old and poor-quality buildings, which will all be demolished and rebuilt.

Table 4-4 Timing and Content of Renewal and Retrofit in Case Communities

<table>
<tr><th colspan="2">Name of community</th><th>Hongyupo, Chongqing</th><th>Heyi, Shenzhen</th><th>Dongtang, Jiangshan</th></tr>
<tr><td colspan="2">Year of retrofit</td><td>2023-2026</td><td>2023-2026</td><td>2025-2035</td></tr>
<tr><td colspan="2">Number of permanent residents after retrofit</td><td>14,200</td><td>8,822</td><td>1,734</td></tr>
<tr><td colspan="2">Gross floor area (m^2)</td><td>392,152</td><td>177,274.9</td><td>46,800</td></tr>
<tr><td colspan="2">Green retrofit ratio (%)</td><td>27%</td><td>100%</td><td>100%</td></tr>
<tr><td rowspan="4">Content of retrofit (m^2)</td><td>Residential building area after green retrofit</td><td>99,668</td><td>160,557.9</td><td>0</td></tr>
<tr><td>Demolished floor area</td><td>7,357</td><td>7,565</td><td>46,800</td></tr>
<tr><td>Reconstructed green building area</td><td>7,357</td><td>0</td><td>46,800</td></tr>
<tr><td>Structurally reinforced building area</td><td>19,933.6</td><td>0</td><td>0</td></tr>
</table>

4.2.3 Carbon Accounting for Building Retrofit in Case Communities

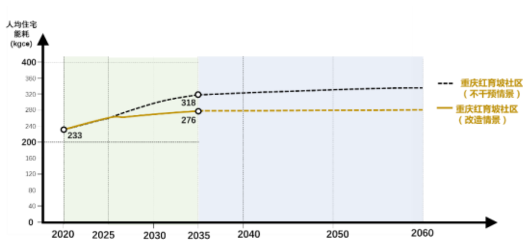
According to the retrofit methods, areas and schedules of the three case communities, and based on the aforementioned carbon emissions per unit area of different retrofitting stages, the total carbon emissions from retrofit in each community over the years are calculated and shown in Figure 4-8. The total carbon emissions from green retrofit and demolition in Heyi community are 38,900 tons, from demolition and reconstruction in Dongtang community are 30,400 tons, from green retrofit, structural reinforcement, demolition and reconstruction in Hongyupo community are 31,700 tons. The accounting results show that building retrofit significantly increases the total carbon emissions of communities. During the retrofitting period, carbon emissions in relation to the retrofit in each community reach five to six times of the aggregate emissions from normal building operations (2020 baseline) per annum, and 1.5 to 2.2 times of the total annual carbon emissions of the community (2020 baseline), indicating that building retrofits are highly carbon intensive. From the perspective of energy efficiency and carbon reduction in buildings, green building technology should be used as much as possible in retrofit projects in the future to minimize the need for further energy-efficient retrofits. Meanwhile, carbon emissions from retrofit should be reduced as much as possible. In addition, efforts should be made to avoid demolition and reconstruction when buildings are still usable.

4.2.4 Comparison of Energy Consumption Curves between Renewal and Green Retrofit in Case Communities

Hongyupo community and Heyi community will **demolish a small number of buildings and retrofitted low-quality buildings using green methods**, such as improving insulation, enhancing lighting & ventilation, and using energy-efficient appliances. The energy consumption of lighting, heating, cooling and hot water is lower than the scenario without the green retrofit. The current building energy consumption in Hongyupo and Heyi communities is low. With the increase in the use of air conditioning and home appliances, per capita energy consumption still shows an upward trend. However, the green building retrofit will help significantly reduce the peak energy consumption in 2035, and substantially contribute to energy conservation. Specifically, if Hongyupo community partially replaces gas water heaters with air source heat pumps for higher energy efficiency, the total building energy consumption can be reduced by about 13%. As heating and cooling accounts for a smaller share of energy consumption in Heyi than Hongyupo, the energy savings of about 6% are less significant. Therefore, green building retrofitting methods should be promoted in the building renewal of old communities for energy conservation and emission reduction.

Dongtang community will **demolish all the existing buildings and rebuild green ones**, which will significantly improve building energy efficiency. The current per capita building energy use in Dongtang community is rather low, which will increase significantly in the future. If the renewal is to be completed by 2035, the increased energy demand for heating and cooling can be drastically reduced, according to the 65% energy-saving standard of green buildings. The total building energy consumption in Dongtang community in 2035 can be reduced by about 19% compared to the scenario without renewal, which saves a great amount of energy.

Hongyupo, Chongqing



Heyi, Shenzhen

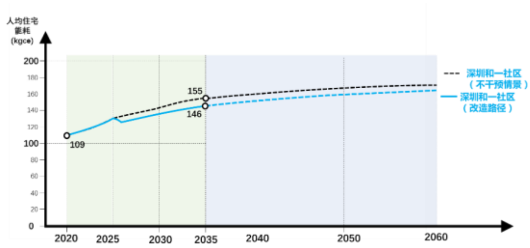


Figure 4-6 Comparison of Building Energy Consumption between Green Retrofit and Business-as-usual Scenario in Hongyupo and Heyi

Dongtang, Jiangshan

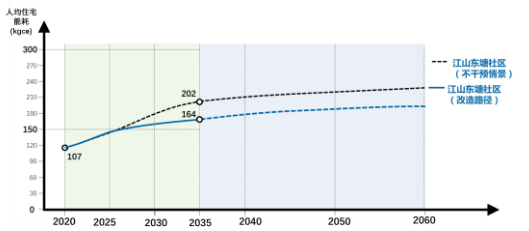


Figure 4-7 Comparison of Building Energy Consumption between Green Retrofit and Business-as-usual Scenario in Dongtang

Heyi, Shenzhen

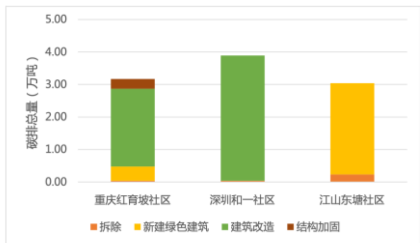


Figure 4-8 Carbon Emissions from Retrofits in the Three Communities

4.3 Difficulties and Challenges in Decarbonizing Urban Communities

4.3.1 Residential Energy Use

The case study shows that the future demand for building energy consumption (especially electricity) will grow significantly, driving up national carbon peak and making it more difficult and costly to achieve carbon neutrality. Therefore, the key tasks in the residential energy use sector by 2035 include effectively reducing building energy consumption through green technologies, implementation of green retrofit techniques in buildings through community renewal, and advocating green lifestyles, so as to control the excessive increase of residential energy consumption.

During 2035-2045, building energy consumption in case communities will reach its peak. The key tasks in the residential energy use area from 2035 to 2060 are reducing energy demand by improving equipment energy efficiency, replacing natural gas through electrification, cutting direct carbon emissions with distributed renewable energy, and eventually achieving carbon neutrality through decarbonizing the grid.

4.3.2 Mobility

Emission reduction in mobility concerns three main aspects: demand, mode and energy use. As new energy vehicles account for less than 2% of the total, they are not able to play a leading role in restructuring energy mix of the transport sector before 2035. The key to control energy demand of mobility by 2035 is to effectively transform mobility structure with green methods whilst reducing the number and distance of trips through optimizing urban functions and services.

In 2035, green mobility (public transport + non-motorized vehicles + walking) of case communities may account for over 80% of the total, which leaves limited room for reducing energy consumption through modal shift. So the key task of cutting carbon emissions from 2035 to 2060 is to optimize the energy mix in the transport sector. As energy efficiency reaches its limit, the focus of further reduction of energy consumption and carbon emissions should be on replacing fossil fuels by clean energy for motorized transport.

4.3.3 Municipal and Daily Living

First, the promotion and practice of green lifestyles in communities should start as early as possible. As living standards improve, water consumption, domestic waste generation, and animal-based food consumption will continue to grow. At the community level, it is necessary to prioritize quality of life for residents, whilst improving their acceptance of a green lifestyle. Considering the time required to promote and popularize green lifestyles such as water conservation, waste separation and saving food, community-level carbon peaking may lag behind the set national target.

Second, investment in infrastructure and green equipment should be fully guaranteed. For water management services, efforts shall be made to renew municipal pipe networks, and apply new sewage collection and rainwater utilization technologies. For domestic waste, carbon reduction can be achieved mainly through efficient waste separation. For food consumption, rooftop farms, vertical farming, and community canteens can help cut emissions. These facilities should be implemented as a priority and require substantial financial support.

Third, extensive and concerted efforts are necessary to realize the carbon neutrality goal. Since municipal and daily living areas are the basic needs of residents, carbon emissions will go down somewhat after green retrofits, but the overall impact is rather limited. Near-zero CO_2 emissions by 2060 are not possible with community-level improvements alone.

5. Recommendations on Community Green Renewal and Green Technology under the Goals of "Peaking Carbon Emissions by 2030" and "Achieving Carbon Neutrality by 2060"

In the first phase of SPS on green technology of CCICED, Chinese and foreign experts jointly proposed six key areas of urban green technology development and offered 20 recommendations on piloting green technologies during the 14th Five-Year Plan period. Overall, these technologies focus on technological readiness, emissions-reduction benefits and financial viability.

While the second-phase study is implemented on community level, the technology application at the community level is more complex and diverse, and many differences across communities and the applicability of recommendations need to be considered for the promotion of green technologies. In particular, in the context of China's commitment to the Goals of "Peaking Carbon Emissions by 2030" and "Achieving Carbon Neutrality by 2060" (the Goals), the contribution of green technology recommendations to the realization of the Goals are considered.

5.1 Understanding and Responding to the Goals and Community Diversity

5.1.1 Differences of Green Development Strategies for the Two Phases under the Goals

The carbon emissions measurement and demand analysis of the communities in the case study show that while the current per-capita community carbon emissions are not high, there will be a huge increase in demand in the future. Therefore, unlike the singular focus on carbon emissions reduction seen in the developed countries of Europe and America, attention should be paid to the differences between the two phases for green renewal and green technology promotion in Chinese communities:

Phase I: Before peaking carbon emissions by 2030, priority should be given to meeting the new living needs of residents in a green way, scaling up the application of mature green technologies, promoting green lifestyles, and reducing the peak value.

Phase II: Before achieving carbon neutrality by 2060, the application of innovative green technologies in communities should be comprehensively promoted, along with the shaping of a green lifestyle and governance system to achieve net-zero emissions.

5.1.2 Three Cognitive Dimensions from the Perspective of Community Diversity

Community diversity and demographic complexity in community green renewal and green technology adoption must be fully taken into account. To understand the differences among various communities, the following three dimensions, at the minimum, must be considered:

(1) Population-group profile. There are four population types: aging, upper middle-income, lower middle-income, and young migrant tenants. The income level and willingness for long-term improvements vary among the four groups.

(2) Building features. The case communities represent four main types of Chinese communities: old communities of collective housing, old communities of private housing, sub-new communities built after 2000, and villages in city. There are significant differences among the four types of communities in terms of renewal ownership, retrofit model, green renewal requirements and pathways.

(3) Resource endowment and basic conditions. There are great differences in the richness of renewable resources in the case communities. The Heyi Community is located in an area with rich renewable energy (i.e., solar energy and wind energy); Shanghai and Jiangshan represent areas with relatively good renewable energy sources (i.e., solar energy), and Hongyupo features severe scarcity of renewable energy. Additionally, these communities have different climatic conditions (e.g., the Chongqing, Shanghai and Jiangshan areas experience cold winters and hot summers, and therefore demand heating in the winter) and different locational conditions, which have created diverse needs in promoting green technologies.

5.2 Community-Based Green Technology Recommendations before Peaking Carbon Emissions by 2030

5.2.1 Recommended Building Technologies

Great importance must be given to green building technology. A high premium must be placed on promoting building energy-efficiency improvements and retrofit technologies, as well as adopting intelligent building-management technologies in existing buildings, so as to reduce carbon emissions in the entire building construction and operation process.

Green construction. This includes green building materials, prefabricated construction and decoration, with a focus on low-carbon, pollution-free and low energy-consumption local materials and certified green building materials. Prefabricated construction and decoration can improve quality, reduce material consumption and on-site construction energy consumption, and ease the disturbance for residents caused by construction.

Building energy efficiency improvements and retrofitting. This mainly concerns the energy-saving transformation of the enclosure structure to improve thermal performance, including using energy-saving doors and windows, adding shading facilities and thermal insulation layers, changing flat roofs to sloping roofs, adopting light color finishes, etc.

Three-dimensional greening. This refers to the greening technologies for building roofs, overhead floors, balconies, windowsills, wall surfaces or other parts involving the building structure, maintenance management system and/or plant selection. These technologies are expected to bring multiple benefits, such as improved thermal performance, improved microclimate, locally produced food, newly added carbon sinks, recovered biodiversity, etc.

Intelligent building management. Online monitoring, cloud computing, the Internet of Things (IoT) and other technologies are adopted to monitor and adjust the dynamics between energy supply and consumption in real time. Monitoring the key energy consumption equipment and analyzing the energy consumption rate can help to understand the proportion and trend of energy cost and to inform the development of energy efficiency strategies.

5.2.2 Recommended Energy Technologies

Energy conservation, electric energy alternatives and renewable energy alternatives are the main direction toward the development of low-carbon communities and the key technical direction of community green renewal.

Energy-saving appliances and equipment. Energy-saving appliances, such as high-efficiency air conditioners and water heaters using heat pump technology, can prevent the increase in energy consumption caused by more frequent use of new household appliances. Furthermore, these appliances can also contribute to the increased efficiency of public energy consumption in the communities.

Distributed energy development and utilization. The utilization of distributed energy, including solar energy (photovoltaic, photothermal), wind energy, shallow geothermal energy, air source heat pumps and other renewable energy sources, and the adoption of natural gas combined heat, power and cooling systems are key in reducing community-based carbon emissions.

Multi-energy complementary energy supply. In communities powered by distributed energy, the combination of traditional energy systems with distributed energy systems and energy storage can ensure both the prioritized use of distributed energy and the efficient, low-cost utilization of traditional energy. For the purpose of adopting this technology, communities need to build new complementary energy stations on their idle land, or to transform and upgrade the existing heat stations and substations.

Smart energy management. The community energy supply system can be renovated in a smart way by adding load-side online monitoring, key energy-consuming equipment monitoring, and energy supply and energy storage active response facilities to keep a balance between energy supply and demand.

5.2.3 Recommended Technologies and Strategies for Mobility

Strategies for the improvement of walking and cycling conditions. The pavement can be improved and a pleasant environment can be created to control the speed of vehicles and guide the traffic flow, while enhancing the convenience and comfort of non-motorized traffic, driving a shift toward low-carbon mobility options. Non-motorized traffic can be smoothly and safely connected through urban overpasses, public buildings and open space. Depending on the local landform and climate, more diversified lanes can be added in the form of vertical traffic, covered corridors, and "wind and rain" corridors.

Bus and rail connection optimization. Efforts should be made to make public transport more attractive by designating non-motorized traffic lanes and adding community entrances, bus stops and rail transit-station entrances. During peak hours, bus services can improve the connection between communities and bus/subway stations and thus increase the penetration of public transport.

Shared mobility refined management. On-demand allocation of shared vehicles (cars, bicycles, e-bikes, etc.) has the potential to improve the utilization rate of shared mobility.

5.2.4 Recommended Technologies in Municipal Water Service

Improving the efficiency of the internal water supply and drainage units during community renewal is the main technical direction for improving the overall operational efficiency of the urban water system and reducing water-related carbon emissions.

Community sewage quality improvement and efficiency enhancement (rain and sewage diversion). At the community level, renewal efforts should be focused on rainwater and sewage diversion and eliminating wrong connections of rainwater and sewage, so as to realize shallow drainage of rainwater and centralized treatment of sewage through pipes, and improve the efficiency of sewage collection. Community septic tanks should be gradually eliminated to reduce emissions of non-carbon greenhouse gases such as methane and nitrous oxide and increase the sewage concentration, which is conducive to energy conservation and emissions reduction of sewage treatment.

Community low impact development. Sponge communities can be built to strengthen the utilization of rainwater resources at the source and ensure the safety of waterlogging prevention. Communities should optimize the vertical design of the site and properly allocate plants by combining green and gray elements to further green the infrastructure.

Community Non-Revenue Water (NRW) Management. According to layout of water sources and topographic characteristics, communities should optimize the layout of community water supply access, the water supply pressure at the access point and the secondary water supply method; and reduce the leakage from across the pipe network. Meanwhile, they should also strengthen night flow supervision, accelerate the renewal of old and/or damaged water supply pipelines, speed up the transformation of rainwater and sewage diversion, reduce the amount of rainwater entering the sewage system, improve rainwater utilization and turn sewage into resources.

5.2.5 Recommended Technologies for the Treatment of Domestic Waste

Treatment processes have a great impact on the final carbon emissions of domestic waste. It is vital to reduce emissions from the source and optimize the treatment model.

Household kitchen waste crushing and dehydration. Special household electrical equipment should be developed to dehydrate or crush kitchen waste. Residues can be dried or discharged into the sewer to reduce the workload of sorting, collection, storage and transportation.

Smart waste sorting and recycling. Methods such as the robot arm, air separation and magnetic separation can be used to realize automatic, continuous and large-scale waste sorting and recycling, while data can be collected and uploaded to improve the proportion of recovered resources.

5.3 Recommendations on Community-Based Integration of Green Technologies

5.3.1 Suggestions on Integrating Green Technologies in Community Renewal

In renovating these communities, the biggest challenge lies in the conflict between renewal needs and limited funds. To address this issue, a gradual approach should be considered, starting from the areas requiring fewer investments and producing higher returns. The green renewal of old residential communities should be focused on such areas as utilities, public transport and buildings.

1) Municipal water service. Efforts should be taken to upgrade old and/or damaged water pipes, eliminate septic tanks and build sponge communities to reduce water consumption and resulting carbon emissions. 2) Transport. Given the inadequate parking lots in old residential communities, optimized bus/rail transit feeder systems should be combined with enhanced options for walking and cycling to increase the comfort and convenience of slow mobility and shape a greener mix of mobility options. 3) Buildings. In reducing emissions from this sector, non-technological methods should be first considered, such as reducing the vacancy rate of buildings and creating a public living space. Priority should be given to renovating existing building by adopting energy efficiency improvement technologies, such as environmentally- friendly doors and windows as well as external wall shelters, which require less investment but yield quick benefits. In the retrofit of buildings, green building technologies should be strictly adopted and in terms of public buildings, three-dimensional greening should be actively advocated.

5.3.2 Suggestions on Integrating Green Technologies for Renewal of Ageing and Middle/Low Income Households and Communities

For the ageing, mid- and low-income population groups, green renewal should fully take into account their limited resources, as well as low rates of energy consumption and mobility. Low-cost technologies are encouraged to reduce living costs, along with carbon abatement.

1) Transport. An increase in convenient, lost-cost and low-carbon transport options can increase the mobility of mid- and low-income groups. More favorable walking conditions can enhance safety and comfort for the elderly. Therefore, like that of old residential communities, it is also a top priority to build a more effective bus/rail transit feeder systems and create more enabling conditions for walking and cycling for the elderly. 2) Buildings. Building retrofits should go hand-in-hand with improvement efforts in the public environment of communities. Through measures such as changing doors and windows, adopting external wall insulation and improving ventilation and natural day lighting, carbon emissions can be reduced while also improving the comfort and cost for this population group. When it comes to community-based public buildings, high-performance energy efficiency improvement technologies are suggested to create a comfortable networking and living space outside the home.

5.3.3 Suggestions on Integrating Green Technologies for the Renewal of Communities with Abundant Renewable Resources

The communities in China's economically developed regions are and have been ready for the comprehensive use of green technologies and full use of renewable energy. For instance, Shenzhen Heyi Community, with abundant solar and wind energy resources and relatively clear rural collective property rights, has prepared itself for comprehensive green renewal and should be encouraged to build a model area for low-carbon or even zero-carbon development.

1) Energy. Great efforts should be taken to promote the development and use of distributed energy resources and the supply of complementary energy sources and integrated applications of renewable energy technologies, including DC microgrid and energy storage. 2) Transport. New energy vehicles should be actively scaled up and associated charging stations should be proactively explored. 3) Buildings. Near-zero carbon and zero carbon buildings, which are focused on increasing energy efficiency, should be promoted while applying smart building technologies and three-dimensional greening technologies. 4) Regions with scarce renewable resources are discouraged from indiscriminately using costly green technologies in the areas of energy and buildings and from developing zero-carbon residential communities.

In addition, for Dongtang Community where the land is privately owned and the renewal efforts are undertaken by each individual household, special attention should be paid to the features of the ageing and low-income groups and to the integrated application of low-cost, distributed technologies. Green technologies should be highly integrated for building retrofits, green renewal and municipal utilities.

5.4 Suggestions on Innovating Green Technologies for the Goal of Achieving Carbon Neutrality by 2060

As part of China's effort to achieve carbon neutrality by 2060, community-based green renewal must focus on deep carbon abatement and the innovation and application of green technologies. In the first phase of SPS, CCICED has recommended 12 green technologies which should be continuously implemented in the second phase. To address the community needs and application scenarios, the second phase has added some new innovative and scalable green technologies to strengthen systemic interventions and achieve the goal of carbon neutrality.

Table 5-1 Recommended Green Technologies in Six Key Areas during the 14th Five-Year Plan Period

Key areas	Technological focus	Recommended technologies
Water	Sewage treatment and water recycling economy	Sewage treatment and plant-network-river integration
	Utilization of recycled water	Quality protection of recycled water
	Utilization of recycled water and NRW management	Smart operation of recycled water system
Energy	Integrated grid powered by green energy	Microgrid
	Near-zero carbon cooling and heating	Central heating by using industrial waste heat
		Utilization of medium-deep geothermal energy
	Internet of Energy	Integrated management platform of the Internet of Energy
Transport	Smart mobility system	Mobility as a Service
	New energy vehicles and supportive facilities	Hydrogen vehicle
		Smart charging system
	Traffic demand management and cycling	Bicycle route
Buildings	Healthy buildings	Three-dimensional greening of buildings
	Green buildings	Steel structure+internal modular space
	Near-zero-energy consumption buildings	PV, BIPV, distributed energy storage and DC power supply
	Smart operations and maintenance of buildings	Networked smart building systems
Land planning and use	Green urban landscape	Technology kit for green urban landscape
	Green, livable and carbon-neutral communities	Technology kit for building green, livable and carbon-neutral communities

Food	Food tracing	Food safety information monitoring and tracking
	Urban farming	Vertical farming
	Smart agriculture	Digital food platform

5.4.1 Recommended Innovative Technologies in the Field of Energy (new)

Hydrogen utilization and fuel cells. This technology can be used in buildings after breakthroughs in technology and cost. Renewable energy for hydrogen production, large-scale hydrogen storage, natural gas pipelines for hydrogen transmission and hydrogen-powered fuel cells will come together to form a complete hydrogen production and supply ecosystem, which can ensure diversified supply of energy and urban energy security. It is noteworthy that fuel cell technology has the potential to replace natural gas-powered heating and cooling system in the communities.

Efficient air conditioning. This refers technologies with a coefficient of performance (COP) not less than 7.0. There has been a sustained growth of energy efficiency in the leading air conditioning products in recent years, which is accelerated by the adoption of heat pumps. Currently, large air conditioners, with a COP of more than 12, have appeared on the market. Looking forward may be the advent of smaller but more efficient air conditioners which are easy to be installed and used at home.

Blockchain. In trading community energy, point-to-point transactions in particular, blockchain technology will play a vital role in shaping the distributed power trading programs and policies of electricity pricing.

5.4.2 Recommended Innovative Technologies in Treating Domestic Waste (new)

Low-carbon garbage collection pipeline. Negative pressure technology can be used to pump domestic waste and transmit them to a central garbage station via dedicated pipelines before delivery to a garbage disposal plant by compressed vehicles. The fully automated process can ensure a very quick and clean collection of garbage.

Garbage incineration power generation. Domestic waste with higher calorific value are incinerated for power generation to reduce landfills, soil pollution and carbon emissions while recycling the waste to heat energy.

Anaerobic fermentation of kitchen wastes. Kitchen wastes can be treated at a large scale through anaerobic fermentation to recover crude fat, solid residues and liquids for the recycled use of biomass resources and for biogas power generation.

Distributed aerobic composting of kitchen wastes. The kitchen waste collected within a community can be treated using aerobic composting to decrease the ratio of collected, stored and transported wastes, and produce organic fertilizer. As a result of this technology, kitchen waste can be directly treated for the purpose of green conservation.

6. Promoting a Green Lifestyle through Community Green Renewal

In promoting a green lifestyle, there are three focus areas. First, low-carbon consumption can be promoted by encouraging the purchase and use of green, low-carbon products. Compared with conventional products, these low-carbon products consume less energy, emit fewer greenhouse gases and have a longer lifecycle. To shape a green lifestyle, greener mobility choices and low-carbon diets are also called upon. Second, reduction can be encouraged with an emphasis on reducing the carbon emissions from the reduced use of various household appliances and some transport options. And third, carbon chains can be shortened by reining in activities. For example, efforts can be made to change the patterns and places of working and learning (e.g., remote working/learning) to reduce the carbon emissions from daily commuting.

6.1 Low-Carbon Consumption

Buy low-carbon daily necessities. 1) Check the energy label when buying an electrical appliance and choose one with higher energy efficiency, such as energy-saving lamps, water saving toilets, inverter air conditioners and inverter refrigerators, which can translate into more than 10% savings in energy consumption and carbon emissions. 2) Buy products powered by clean energy (e.g., solar), including home electrical appliances such as solar water heaters and solar street lamps. 3) Choose durable and renewable products that produce less pollution, such as those made from degradable materials and non-disposable goods. 4) Purchase goods either without packaging or with less or recyclable packaging. 5) Avoid using products containing micro-plastics commonly found in facial cleansers and shower gels, and use green alternatives instead.
Choose green mobility options. Rail transit is suggested for medium- and long-distance mobility while walking and cycling are more suitable for short-distance mobility. As shown in the carbon footprints of various mobility methods released by the Department for Business, Energy & Industrial Strategy in 2018, rail transit emits less carbon than automobiles. In terms of short-distance commuting, cars are ranked higher than buses, motorcycles, subways, bicycles and walking (in a high-low order of

carbon emissions). The publication mentions that the smaller a vehicle is, the less carbon it emits. Another finding is that electric vehicles (EVs) and Plug-in Hybrid-Electric Vehicles (PHEVs) only produce roughly one third of the carbon emissions of gas/diesel-fuelled vehicles.

Practice a low-carbon diet. Low-carbon food such as fruits and vegetables are encouraged to reduce the carbon emissions associated with farming practices. Research shows that from the perspectives of unit weight and unit protein supply, plant-based foods, including fruit and vegetables, emit less carbon than animal-based foods (e.g., meat and dairy products), while fish, poultry and pork outperform ruminant animal-based food.

Advocate moderate consumption to reduce waste. A prudent judgement of needs, a simple lifestyle, and a moderate level of consumption can reduce the waste arising from unwanted and redundant consumption. Irrational behaviors like impulsive purchasing and giving in to merchants' promotion activites should be avoided. Food should not be wasted and a proper amount of food should be bought, including ordering moderate meals in restaurants. Research[32] shows that on average, every Chinese person wastes 44 kilograms of food every year, ranking China 22nd in the world for most food waste. In fact, the yearly wasted food in Chinese cities is comparable to total staple food imports.

6.2 Reduced Use

Reduced and greener use of household appliances. 1) Efforts should be made to reduce reliance on electrical appliances. This can include, for instance, washing by hand instead of washing machines and dishwashers, traditional toothbrushes over electric toothbrushes, natural air drying over clothes dryers, brooms over vacuum cleaners, spring-wound alarm clocks over electronic clocks, and avoidance of elevators for lower floors; 2) Outdoor activities can be increased and indoor fitness devices should be spared to reduce the energy consumption arising from the use of lighting and air-conditioning systems associated with indoor sports; and 3) household appliances and drinking watercan be used in an energy-saving and low-carbon manner. Meanwhile, energy-efficient household appliances and smart home control systems can be adopted to reduce energy consumption while satisfying the needs of daily life. For example, air conditioning and heating systems can be set at a temperature close to outdoor temperature. Remembering to switch off the cooling or heating system when a room is vacant, shutting off the air conditioner when leaving the home, switching off the lights or taps at any possible opportunity, starting a washing machine or dishwasher only at full capacity, and cutting off the power supply when a household appliance is not being used are other actions to attempt.

Shared mobility. Ride-sharing should be encouraged to reduce the carbon emissions of each individual and diminish residents' enthusiasm for buying private cars. Network operators can join hands with residential communities and other stakeholders to build a shared mobility platform so that residents can identify common routes and time schedules for the benefits of shared mobility. This platform is particularly useful for those on the same commuting route for work or school.

Recycled use. Renewal of wasted items or trade-in can be promoted to recycle daily supplies and extend their lifecycles, while eliminating the need to dispose of, remanufacture and/or resupply those items. Recycled use, however, requires the support of communities, which can encourage and teach residents to renew used items, develop flea markets for trading used items and building online platforms for second-hand transactions.

6.3 Shortened Carbon Chains

Working and learning remotely from home. An online platform can reduce the need for commuting to work and school. Some jobs, such as IT, media and language mentoring, can be done via online platforms. Even when only a partial share of jobs are performed remotely, carbon emissions can be reduced remarkably. Research indicates that if 100 people work from home for three days a week, GHG emissions can be reduced by 70 tons throughout the year[33]. Companies must create adequate conditions for remote work, or this would not be possible.

Growing and eating local food. Urban farming can be practiced in residential communities where residents engage in growing their own farm produce. Residents can be mobilized to grow fruits and vegetables on wasted land or on rooftops. When new farming techniques are combined, vertical farming can prosper, increasing the plantation acreage of greens and crop yields. Such community-based farming practices are expected to reduce carbon emissions from food transportation, packaging and retail sales, while also cutting down on the land use required for growing fruits and vegetables. In implementing the project, CAUPD Shanghai and Chongqing teams experimented growing vegetables and fruits on the rooftop of office buildings, gaining a rewarding and interesting experience.

6.4 Enabling Conditions for a Green Lifestyle

A green lifestyle not only depends on strong will and organization of residents, but also relies on enabling policies, governance mechanisms and facilities.

Policy support. The country or the city should exercise price controls and provide production subsidies for low-carbon products; increase the use of low-carbon product labels; use government procurement in leading green supplies, incldthe low carbon diets, in schools, hospitals, public ministries, state enterprises and other; strengthen the awareness of low-carbon products among communities; and support the purchase of low-carbon daily necessities. City governments and businesses should encourage and enable the practice of working remotely from home.

Governance support. Residential communities should launch dedicated campaigns to teach residents how to refabricate used items and build trade-in marketplaces, such as flea markets or second-hand transaction platforms to support the recycled use of waste products. In addition, programs should be carried out to spread knowledge on using household appliances in a low-carbon manner and promote the reduced, greener usage of these appliances. A central shared mobility platform should also be put in place to enable shared mobility.

Facility support. Cities should build a more user-friendly public transport transfer network near neighborhoods, and install shared charging stations and solar-powered charging stations for new energy vehicles to provide options for green mobility. Residential communities should optimize outdoor public spaces and facilities and build shared spaces for working, learning and catering. Also, spaces such as wasted land and rooftops can be utilized to scale up urban farming.

7 Promotion of Digitized Green Transition in Chinese Cities

7.1 Analysis of Five Factors for Digitized Green Transition

Actions to make cities more livable, inclusive and sustainable have noticeably intensified over the last decades. This shift towards green and sustainable cities converges with another global megatrend which is often referred to as the digital transformation or the Fourth Industrial Revolution (4IR)[34]. The confluence of physical and digital infrastructures in cities bears many opportunities for the green and smart transition of Chinese cities. Table 1 provides an overview of how the key sectors of urban green development could benefit from digital technologies[35]. The five factors, i.e., infrastructure, economy, governance, people, and environment are the key in smart and sustainable urban transitions.

Table 1: Examples of potential digital applications in different sectors to support green urbanization in China

Sector	Potentials application of digital technologies
1: Energy	Enabling of renewable energies, peer-to-peer energy solutions (*prosumer of energy*), increasing energy efficiency, predictive maintenance of energy systems, and improving energy planning
2: Building	Iproving human-centred city planning. Improving light, heat and cooling management
3: Mobility	Enaling new forms of shared mobility, improving mobility systems to reduce carbon and noise emissions, improving public transport efficiency and reducing prices, semi-automated and automated driving
4: Land use	Supporting land use planning processes through data-analytics of resource flows and behaviours of citizens, enabling citizen participation in urban planning processes
5: Food	Enabling participatory urban agriculture and food production, enabling food sharing platforms
6: Water	Improving urban water management, monitoring water quality, enhancing residential and industrial water efficiency

Source: Based on WEF 2020, supplemented by authors.

7.1.1 Infrastructure

The smart cities alter the classical understanding of infrastructure. Infrastructure, such as roads, water, wastewater and electricity supply, waste management and public facilities, are increasingly coupled with a layer of data infrastructure (e.g., sensors and networks) and linked more closely with urban management and public services. In this way, digital technologies and the collection of data can support the efficiency, reliability, and sustainability of classical hard infrastructure on multiple levels, make infrastructure more durable, and decrease the resources used to rebuild them. Digital technologies can also manage complex systems, enhance the flexibility of urban systems (e.g. electricity supply), promote the opening of the renewable energy integration, monitor environmental conditions, and better manage infrastructure.

However, digital upgrades of infrastructure are costly and need skilled management and application abilities. Furthermore, digital technologies can also create new vulnerabilities which pose a threat to their resilience. Cyber-attacks on infrastructure, for instance, may lead to severe damages[36]. Upgrading physical infrastructure with digitization therefore requires new and holistic concepts to strengthen the resilience of these systems. Technological solutions should be considered less as “technical fixes,” but viewed more holistically with regard to their interaction with society and the environment, as well as possible new vulnerabilities and risks.

7.1.2 Economy

Datafication of urban spaces is regarded as an important economic factor and driver for innovation. Data can be used by businesses in production and the service industries to improve the efficiency of their operations, track environmental impacts, and improve processes, thereby reducing resource consumption. In this way, businesses can reduce carbon emissions. Data provided by public institutions or generated in urban spaces can help businesses develop new products and services for their customers that serve their needs better and are less pricy.

If urban data ecosystems and their governance systems are not carefully or effectively designed, power imbalances or data divides – and therefore imbalances in competitiveness and value-creation from data – can likely be created and eventually hamper learning, innovation and putting data to use for the common good. Therefore, cities need to carefully design their data governance schemes to support the kind of innovations they aim for to become smart and carbon-neutral.

7.1.3 Governance

The digital technologies in city spaces can contribute to changing urban governance. Data can create a better understanding of the flow of materials, vehicles, and people and help local authorities and administrations to better serve the needs of citizens and businesses. Digital systems can also allow citizens to provide direct feedback to their administrations, foster learning processes in communities and enable citizens to become an active part in city governance. Data about the habits and preferences of citizens can not only be used to increase their quality of life, but also help improve the planning of urban spaces. Environmental monitoring data can help manage the city's resources and improve the quality of living. Data can also identify accident blackspots, quickly discover environmental or natural hazards, and provide inhabitants with the safety information. The digitization of cities can therefore improve urban disaster and risk management abilities.

However, digital technologies in cities also create risks and challenges for citizens and local authorities[37]. Digital technologies can help to manage complexity, but they themselves are also complex and create new puzzles. Cities in developing countries of the Global South struggle with building their own capacities to deal with the challenges of digitalization[38]. Instead, they often depend on technology providers, which compromises their ability to choose the technological settings that serve their needs best. Moreover, ICT companies often deliberately position themselves in the control position of the deployment and management of smart cities in order to yield benefits from urban data flows[39].

Furthermore, a lot of data does not necessarily lead to a lot of more valuable new insights or better decisions[40]. Administrations need the capacities and competencies to understand and make good use of the data and know its value against the real-world problems of city dwellers. Otherwise, instead of supporting the good and participatory governance, digital tools could make the governance efficiency lower, and even overburden local authorities.

7.1.4 People

Smart green cities should put the quality of living and the needs of people in the center. Smart cities can allow residents to benefit from the quick processing of energy, transportation, public services, and administrative matters. In particular, as mentioned above, digital technologies can facilitate a direct dialogue between citizens and their local authorities and administrations, communication between residents, and improve community consciousness and resilience in times of hardship. Furthermore, digital technologies can enable vulnerable groups to support each other and find solutions for their needs and challenges, therefore spurring social innovation. Open data can provide citizens with the information they need to pursue their aims and interests and enable them to take part in the development of their city. Please see Annex I for an in-depth analysis on the sharing economy and the climate.

However, digital technologies are no guarantee for inclusiveness – often on the contrary. There is still, even in technologically advanced societies, a large digital gap, mostly along the lines of gender, age, income, and digital skills. Digital services and tools need to be designed and implemented in a way that create benefits and are suitable also for marginalized and disadvantaged groups and avoid exclusion and disadvantages. A truly inclusive strategy for digital services could furthermore include additional offline services to enable the digitally disadvantaged to communicate with local authorities, businesses and other people. Moreover, the ubiquity of data generating technologies in smart cities have raised concerns with regard to the protection of privacy and personal rights, and the concept of smart cities has been controversially discussed. Given the potential pitfalls and risks of datafication of public spaces, cities need to carefully consider the use of data-generating technologies, enhance transparency about their application, and protect the rights of individuals. Please see the Annex II for a case study on 'Smart City Quayside in Toronto'.

7.1.5 Environment

Digital technologies can help improve the environment and decrease the carbon footprint in cities. ICTs can manage decentralized energy systems of renewable energy and lower the energy consumption of cities. Furthermore, digital technologies can be put to use for alternative mobility, such as ride- or car-sharing. However, such solutions may not be climate friendly and entail significant downsides.Besides, digital technologies themselves have a large environmental impact. Studies vary in their estimates, but it is reasonable to assume that in 2020, ICTs were accountable for 1.8 to 3.2 percent of global carbon emissions[41] which are expected to increase greatly in several decades. There is a big indeterminacy in the overall environmental impact of edge computing, distributed ledger technology (DLT) and 5G. Moreover, there is also a lack of data on rare earth metals and other resources in the use of raw materials; these precious resources are often exploited under conditions which are very harmful to people and the environment, and only a small proportion are recycled. The Global E-Waste Monitor estimated that worldwide 53.6 million metric tons (Mt) of electronic waste were generated in 2019, with an increase of 21 percent in five years[42], and only 17.4 percent of it was recycled.

It is therefore challenging to assess the full environmental impact of digital systems and whether they have a positive or negative impact on improving transportation efficiency. Against the backdrop of the currently incomplete knowledge about the environmental impact of digital technologies, it is advisable to carefully consider the large-scale use of ICTs in urban settings. The ecological and social value needs to be carefully assessed before implementation, operationalized by meaningful and measurable indicators and monitored and evaluated closely during the use phase. Moreover, in order to improve life-cycle assessments of digital technologies and systems, data about resource usage in the production phase needs to be collected. A sustainable digitalization is more and more recognized as a topic for active environmental policy making. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety in Germany launched a “Digital Policy Agenda for the Environment” in 2019 that highlights key principles, goals, as well as concrete measures to align the digital transformation with sustainable development and to put it to use for climate, nature and the environment[43].

7.2 Suggestions on the Green and Smart Urban Transition

The green and smart urban transition does not occur automatically by digitally enhancing traditional infrastructure. It is a complex task that must balance the opportunities and challenges of the use of digital technologies, driving the transition in a holistic way. It also requires an enabling environment that consists of the following elements.

7.2.1 Urban Sustainability Strategy

This urban transformation strategy needs to be anchored in a strong, long-term vision for a sustainable, carbon-neutral city. This vision should be developed in a participatory process with citizens and other stakeholders. It should also include a reflection on the role of technology in the smart and sustainable city, to make technology contribute to reaching it. Rules and principles for the procurement of smart city technologies and data centers should be included in the urban sustainability strategies. Finally, strategic aims need to be formulated in a way that is specific, measurable, achievable, relevant, time-bound (SMART) and be complemented by concrete steps on how to reach them. Strategy implementation should be monitored and regularly communicated to citizens and stakeholders to check the progress and whether the intended purpose is achieved.

7.2.2 Data Governance

Data governance must adhere to laws and regulations set on the national and international levels, especially with regard to the use of data generated on the community level. Cities should develop a data governance strategy jointly with citizens, businesses, and other stakeholders, which supports sustainability goals and serves the public good. Local data governance should carefully consider the social compatibility of digitalization and evaluate the environmental impact of using data [44]. Data governance frameworks should strengthen individuals' data sovereignty, increase transparency, and heighten the accountability of companies and administrations with regard to data generation and use. Data governance strategies should include a strategy for open data so that businesses, academia, society and others can benefit from data and create new business models as well as technological and social innovations. Finally, data governance needs to outline an institutional setting that implements and watches over data governance principles to create a thriving ecosystem that supports data sharing between different actors.

7.2.3 Public Participation

A smart, green, and human-centered city naturally needs to involve citizens in design and planning and improve inclusiveness and equality by particularly addressing problems for vulnerable groups. However, for citizen participation to be real, it needs to be transparent, accountable, and continuous, and requires urban administrations and institutions to continue learning. Furthermore, the participatory planning should be communicated with regard to the process, problem solving, and results. They should also be continuously monitored and evaluated in order to motivate further civic engagement.

7.2.4 Experimental and Experiential Spaces

The idea of the green and smart laboratory has gained wide attention internationally. However, in order to explore solutions that work beyond specific niches, cities need to develop new ways of engaging their citizens, businesses, and educational institutions in urban planning and innovation. One way to carry out such responsible large-scale innovation on the urban level is to actively collaborate with a city's education and academic systems. These institutions can play a major role in identifying, developing, and implementing solutions for a green and smart urban transition together with local populations. Moreover, experimental spaces should become hubs for exchange, networking and collaboration of knowledge communities that are not yet or not sufficiently interconnected, forming the communities for research on technology and sustainability.

7.2.5 Capacity Building of Local Authorities

Local authorities or communities need a brand-new skill set in order to manage the green and smart transition. On the one hand, this includes profound knowledge about digital technology trends, potential risks and benefits of ICTs as well as sound practical knowledge about how digital technologies can be put to use for urban administrations in various areas (e.g., urban planning, mobility, urban economy). On the other hand, local authorities or communities need to build up competencies that enable them to interact constructively and dialogue with citizens and local change agents (e.g., businesses and civil society), and engage them in the formulation of data governance strategies or urban planning. To fulfill these requirements, local authorities and communities do not only need competencies and skills, but also sufficient and well-trained staff. Furthermore, in order to deal with the complexity of the smart and green urban transition, local authorities need adequate internal systems, cultures and an understanding of their own role that supports learning processes, exchange, and co-creation.

7.2.6 Finance for Transition

Finally, the creation of the aforementioned enabling environments requires sufficient financial support. One of these financial means could consist of dedicating a certain percentage of spending for local infrastructure projects to the implementation of a co-creative process involving citizens and stakeholders in the planning and implementation of digital infrastructure projects. Furthermore, two kinds of incentives need to be provided for companies: on the one hand, adequate incentives and regulations must be put in place to support and encourage private investments in sectors and projects that advance the sustainability transformation of cities; on the other hand, companies need incentives to promote the sustainability benefits of digital business models, services or other products. A "green and smart urban transformation fund" could, for example, support eco-startups in developing new digital business models and solutions that serve the smart sustainability strategy. Finally, investors could be assisted with clear guidelines on how to evaluate the social, ecological, and economic sustainability of a company to support sustainability-oriented investment decisions.

8 Creation of the Enabling Environment for Deployment of Green Technologies

8.1 Key Challenges to the Deployment of Green Technologies

From desk research and consultations with experts and inputs from over 20 large national and multi-national corporations with business operations located in China, challenges to the scaling-up of green technologies in six fields (i.e., energy, mobility, building, land-use, water and food) due to technological, regulatory, and social barriers were identified. The six fields also face financial and economic challenges which cut across the barriers.

8.1.2 Technological Barriers

Besides the issue of the technological readiness of some of the identified, emerging technologies, the bigger issue towards the scale-up of many of these technologies is the lack of infrastructure (hard and soft). The existing energy systems in China do not support the scaling-up of renewable energy. Shifting to the smart energy system will require costly, major adjustments in asset structure. Finally, for NEV charging infrastructure, siting remains an issue for its increased build-out in China. Companies have indicated many hurdles they run into during the implementation stage, including land-use approval, connectivity to the grid, safety concerns to the grid and neighborhoods, and compliance with environmental and city planning regulations.

8.1.3 Regulatory Barriers

Carbon neutrality is a complex issue which touches upon all industries and sectors of the economy. There is a lack of cross-cutting collaboration mechanisms which gather experts from all industries and sectors. A mechanism for data sharing between companies, as well as with researchers, is currently lacking but essential for a successful net-zero transition. Food systems researchers have stressed the lack of access to the vast amounts of data generated by platform companies, which are vital to their work on sustainability in agri-food systems. In the building sector, the current business license management scheme causes a separation between building design and construction, which has caused many difficulties in full-lifecycle management.

Insufficient market mechanisms or skewed pricing prevent adoption of green technologies by the private sector. Carbon capture, utilization and storage (CCUS) technologies, for example, are not yet at the stage of commercial viability, coming across technical difficulties and cost barriers, as well as immature storage and transportation infrastructure. CCUS applied to coal fired power plants can add 14%-25% energy consumption and 20%-30% additional investment cost.[45] Businesses do not have the incentive to invest in CCUS technologies due to the lack of policy and financial support from the government, as well as the low price of carbon.

The absence of a more developed system of standards, certification, and conformity, from public or private institutions, otherwise known as *quality infrastructure*, prevent investment opportunities, cost reductions, and economies of scale for green technologies. 1) In autonomous vehicles, there is no standardization of sensor systems, as well as in communications between the intelligent grid and autonomous vehicles. Along with regulatory barriers such as lack of insurance policy and liability regulations, they are therefore prevented from developing beyond the demonstration stage. 2) The lack of standardization in EV batteries, as well as the lack of compatibility in their interfaces, is one of the main reasons for the immaturity of the battery swapping business. 3) The incompatibility among Chinese and international green building standards constrains the development of green buildings in China. 4) Finally, food labeling for alternative proteins and eco-food is essential in its promotion, but existing labeling either lacks information or is not considered trustworthy, and therefore does little to incentivize Chinese consumers.

8.1.3 Social Barriers

The energy transition faces major social challenges and the coal sector, in particular, is highly affected. In provinces such as Shanxi, the coal sector is one of the largest sources of employment, GDP and tax revenue.[46] Without assistance policies, there will be difficulties for coal sector employees to find new and good job opportunities. The transition will require a workforce that is both highly skilled and familiar with environmental protection. However, skills development strategies have not been currently systematically included in national climate change and green transition policies in China and inter-ministerial coordination mechanisms on training for green skills is lacking.[47] Companies in the green building industry have concurred that there is a large talent gap for a skilled workforce on building full-lifecycle management in the industry.

Increased public awareness, knowledge, and engagement on climate issues can drive wider adoptions of green technologies by urban consumers. Fortunately, most of the Chinese public realizes the importance of adapting to a low-carbon lifestyle, although this level of understanding varies.[48] Consumer demand and behavior changes in terms of diets, forms of mobility, and more can help to drive the scale development and net-zero transition of green technology.

8.2 Creation of the Enabling Environment for Deployment of Green Technologies

The enabling environment for green technology promotion needs joint participation of the national and local government, producers, consumers, financial institutions, and academia. The government should have robust and targeted solutions to break down the various barriers faced by the private sector in the scaling-up of green technologies. Starting with governmental strategic planning and design, as well as stakeholder, cross-sector, and international collaboration, effective policies and financing mechanisms can be implemented, along with the cultivation of a culture of innovation and public awareness.

8.2.1 Strategic Planning and Design

A successful net-zero transition by 2060 starts with a clear, long-term vision and top-level strategic design on the part of the national government to guide technology development and mobilize resources to prevent a misallocation of resources and wasteful missteps. Leaders from government and industry, as well as experts at home and abroad, need to jointly assist policymakers in implementing the right policy instruments and investment actions which support both new technology development and scaled-up deployment of existing technologies. The strategic planning and design should touch upon all sectors of carbon neutrality, especially for the massive investment required for the smart energy infrastructure that incorporates a high percentage of renewables. The build-out of transmission, NEV charging, hydrogen storage, and distribution networks are all components of the smart energy system infrastructure which require strategic design and commitment on the part of the government. Effective governance frameworks can intensify mutual support of city, provincial, and national policies Cities have a major role to play in enhancing data collection and developing data sharing systems (e.g., for energy supply and consumption data), so they can use credible data to establish baselines for setting targets and evaluating progress.

8.2.2 Multi-Stakeholders and Cross-Sector Collaboration

Governments need to work with each other at all levels and between different ministries, as well as with businesses, financial institutions, academia, and civil society, and the stakeholder partnerships will be helpful to formulate policies for promotion of green technologies, and investment into technological innovation and infrastructure. The future smart energy system requires the integration of technologies across sectors, so inter-ministerial cooperation mechanisms must be established. Governments must collaborate with the private sector in technology promotion and data management, and improve the system efficiency by collaboration between different fields and sectors. China has set up a high level climate inrer-ministerial committee, chaired by the Vice Premier and comprised of 17 ministers/agency heads as well as the Vice Premier in charge of economic planning

8.2.3 International Collaboration

International collaboration is also needed, such as the 2021 announcement of US-China collaboration on tackling the climate crisis, which called for more sharing of international best practices, policies and market mechanisms to reduce emissions.[49] The EU-China Climate Dialogue in February this year also provided a forum for pursing ambitious joint commitments on climate issues. The Belt and Road Initiative International Green Development Coalition (BRIGDC), established in 2019, aims to promote international consensus, understanding, cooperation and concerted actions to realize green development on the Belt and Road Initiative (BRI) and to facilitate BRI participating countries to realize SDGs related to environment and development.[50] These frameworks, and more, have laid solid foundations for China to pursue further international cooperation activities. Technology transfer and cooperation on some common global challenges requires global business leaders, leading scholars, governmental officials, and investors to work together to reach technical breakthrough and financial feasibility. International standards and coordination mechanisms will help the global scale-up of green technologies.

8.2.4 Policy Instruments

Preferential Policy: Subsidies, tax incentives, and price policies are important tools for the promotion of green technologies. Non-financial incentives can also stimulate promotion. In the mobility sector, for instance, priority lanes, zero-emission zones, traffic restriction based on license plates, restrictions on car purchase qualification, and so on can all encourage NEV purchasing. The best policies sync multiple solutions and maximize benefits, while at the same time avoid adverse effects. For example, promoting EVs without also scaling clean electrification and a shared economy can result in an increase in emissions from mobility.

Market-Based Mechanisms: The carbon market is an effective policy instrument for companies to internalize the cost of their emissions and as a price signal for companies to shift investments into green technologies. China's carbon market requires further optimization and extension into industries other than the power sector.

Regulation: When factors other than cost hamper accelerated deployment of green technologies, making price signals insufficient, regulations can be a more effective policy instrument. Optimization of the regulatory environment to incentivize SOEs to engage in more innovation and undertake into new business ventures towards green technology and relevant green products and services. For example, the CNOOC, a state oil giant announced the 'Green Development Action Plan' in 2019, with concrete action plans on new business ventures in renewable energy, such as offshore wind. Its first offshore wind project in Jiangsu has been commissioned in 2020.

8.2.5 Financing Mechanisms

Financing the move towards complete carbon neutrality is one of the primary challenges faced by stakeholders. The massive amounts of investment needed for infrastructure and green technology to promote innovation must be met by public and private funding. Government policies need to send market signals for the mobilization of private finance. The public finance on R&D should be prioritized towards green technologies, especially those at early technological readiness stages (e.g., CCUS and hydrogen). The private sector will need to finance most of the investment required for the promotion of green technologies, [51] but the government can encourage the mobilization of private funds by reducing the risk for investors, and adopt suitable policy and regulatory frameworks to attract more private investment. The enhancement of Intellectual Property rights, taxation support, and other mechanisms such as dedicated industrial funds can also support a green-investment-friendly environment in China. On the other side, standardized ESG disclosure can help businesses reduce green financing costs and increase green investment. Public-Private Partnerships (PPP) can help to decrease financial risk for businesses, especially in public infrastructure works such as in the water sector.

8.2.6 Culture of Innovation

Carbon neutrality requires innovation across sectors, especially with the application of

4IR technologies. Innovations in technology, business models, policy, and visionary concepts are the key to fostering a culture of innovation, embracing innovation, and boosting the carbon neutrality agenda. Governments play a central role in creating an environment for innovation in many respects, such as ensuring IP protection, investing in fundamental research, overcoming market failures, providing standards that help market actors coordinate, and providing low cost of capital for innovative technologies.[52]

8.2.7 Public Awareness

Technology scale up and deployment must be combined with human behavioral change, which is why increased public awareness, climate education, and public participation is imperative. Fifty-five percent of emissions reductions require green technology along with active involvement or engagement of citizens or consumers, and 8% from behavioral changes and materials efficiency gains.[53] Governments can also make it easier for consumers to make decisions and choose low-carbon alternatives through quality infrastructure which helps consumers build confidence in the product, such as with trustworthy food labeling for alternative proteins. Governments need to take into account the social and economic effects of the carbon neutralization on people and communities. Making sure of energy affordability, as well as policies that retrain workers, strategically locate new facilities, and provide aid can help to ensure a just transition.

9. Gender and Population-Group Perspectives: Sharing and Public Participation

9.1 The Role of Women in Green Community Development

9.1.1 Women Play a Dominant Role in Green Lifestyles

Women have long outnumbered men in terms of involvement in environmentally-friendly actions. Across different age groups and countries, including China, women are inclined to lead a more eco-friendly lifestyle.[32] Women can play more influential roles in green lifestyles. Due to the traditional division of labor, women spend more time on parenting, caring for the elderly and doing household chores. They have a greater say in making purchases and dietary choices. They place greater emphasis on health and assume important roles in communication and education on sustainability. Women are also more likely to cooperate, gather and communicate, so they find it easier to organize and participate in community improvement programs. Therefore, women are dominant in activities from shaping individual behaviors to advancing green community initiatives. In fact, women's role and leadership are indispensable in many green lifestyle initiatives, from shared laundry services to shared kitchens, elderly care, local green food, low-carbon cooking and education, and used-materials recycling.

9.1.2 Green Development Calls for Women's Engagement and Leadership

Women are more vulnerable to the negative impacts of climate change. Due to deeply entrenched social traditions and economic structures, women are more likely to encounter health, employment and family issues when exposed to a climate change event.[54]Therefore, climate issues must be analyzed from the women's perspective, in order to gain a complete picture of the adverse impacts of climate change and understand the potentially vicious cycle of climate and gender issues.

Female political participation can effectively improve a government's capability in responding to climate change. Countries with higher levels of female political participation are more successful in reducing carbon emissions.[55] Actions taken by European leaders have proved that women are more capable crisis managers than men.[56]Women have proven to be effective leaders in sustainable development. In cities and communities in China, there should be more women assuming leadership roles, where they can help achieve success in technology innovation, inclusion, public engagement and smart and livable city development. They can also help women raise their needs and perspectives in strategic areas of green development, so that women, as important stakeholders and innovators, can also be part of green development.

9.1.3 Women's Enormous Potential in Technology-Driven Green Transition

Science, technology, engineering and mathematics (STEM) are the foundation for innovation, social wellbeing, inclusive growth and sustainable development. The UN points out in a report that "by higher education, women represent only 35% of all students enrolled in STEM-related fields of study" and that "female students' enrolment is particularly low in ICT (3%)."[57] Helping women learn and pursue careers in STEM-related fields will not only help develop more green technologies and improve women's economic stability, but will also strongly motivate women to be part of this technology-driven green transition. In its own right, the green transition also provides an opportunity to address gender gaps and discrimination and promote inclusion and equality.

9.2 Recommendations on Community Renewal that are Favorable for Children and the Elderly

In the debate regarding urban green development, community renewal and the promotion of green technologies, young and middle-aged people usually receive more attention, while children and the elderly are often neglected. However, more and more social issues have arisen as a result of an ageing society and the birth of fewer children. Therefore, models that are friendly to senior citizens and children should be adopted for green community renewal in light of their needs, abilities and adaptability. Studies show that enough open, highly walkable spaces, adequate leisure and service facilities and pleasantly designed environments will encourage children and the elderly to exercise outdoors, increase their social interactions, strengthen emotional bonds and foster a stronger sense of communal belonging, which in turn will also contribute to the promotion of green and low-carbon behaviors. Therefore, the following actions should be emphasized in the green renewal of communities:

1) Organize resources to provide shared elderly and child care services, which can improve community support systems and reduce carbon emissions from day-to-day activities; 2) design rooftop farms, which not only cater to elder people's preferences, but also produce vegetables for household consumption and improve resource efficiency; 3) build more public spaces with low-carbon, anti-slip and permeable materials and provide safe, accessible paths and facilities for the elderly; 4) reduce the depth of water, build gently sloping banks and create playgrounds for children in the retrofit of communities; and 5) use natural landforms and plant materials to build facilities for children to help them feel an affinity for nature and develop green lifestyles. Moreover, communities may also organize the eldely as volunteers for low-carbon and environmental protection activities.

9.3 Recommendations on Community Renewal that are Favorable for Low-Income and Vulnerable Groups

Low-income and vulnerable groups of people, including those who are financially impoverished, unemployed, migratory, informally employed and physically challenged, should also be prioritized in the green renewal of communities. Their voices should be

heard to safeguard their basic rights, help them become independent and empower them to enjoy a high-quality green lifestyle at a low cost. Specific actions may include:
1) Enable more low-income and vulnerable groups to be part of community activities, with their actual needs fully factored in community renewal; 2) build more adaptive public spaces to encourage disadvantaged groups of people to spend less time indoors and assimilate into society; 3) increase the use of natural lighting and ventilation in buildings to reduce the consumption of energy such as electricity and gas; 4) renovate and renew communities in a low-cost manner to prevent expensive homes and facilities; and 5) provide job opportunities from retrofit and renewal and shared facilities to local low-income and vulnerable groups.

10 Policy Suggestions

10.1 Suggestions on Promotion of Carbon Neutrality and Green Development of Cities and Communities

Expedite the National Achievement of System Construction of The "Double Carbon" Goal

Strengthen and extend the coverage of China's carbon market, formulate the carbon price policy, and perfect the carbon trading system; Implement a quota distribution of carbon emissions in industries where it is difficult to reduce carbon emissions, and finally, cover all industries; Formulate an energy transition route map with specific aims and schedules as quickly as possible, and provide guidance for the green transition at the whole overall system level.

Accelerate and Encourage Enterprises to Participate in Low Carbon Development of the Decarbonization Process

Through granting business permit for low carbon products and services, improve the modes such as performance assessments, and promote the leadership of state-owned enterprises in the development of decarbonization and green technologies; Guide private enterprises to participate in green technology innovation and low-carbon product manufacturing, as well as low-carbon building and infrastructure construction through broader multi-incentive policies and constraint mechanisms; Support low-carbon development of mid- and small-sized enterprises and start-up enterprises by the modes such as a "Green Fund"; clarify producers' low-carbon responsibilities for the product life-cycle through the "Carbon Labeling" system; advocate residents to buy low carbon products.

Pay High Attention and Actively Promote Carbon Emission Reduction of Cities and Communities

Formulate an overall carbon-emissions reduction strategy plan at the city level, and propel cooperative transition of energy, building, mobility, land utilization, and infrastructure; Include climate risks into city and community planning; Accelerate the advance of the “zero-carbon cities” pilot project; Construct a batch of “zero-carbon community” demonstration projects; Apply digital technology and AI technology to green management; Design transparent, responsible, and continuous systems and mechanisms, and encourage wide participation of enterprises and the public.

Strengthen Promotion and Application of Green Technologies in Communities

Establish community-level carbon-emissions monitoring and evaluating systems, grasp the present characteristics of carbon emissions in communities, and adopt more effective green development strategies; Quicken the progress of mature green technology application in the fields of energy, building, mobility, municipal administration, etc., and expedite technological innovation and promotion; Speed up perfecting standard specifications for application of low- carbon technologies in communities.

Advocate and Practice a Green Lifestyle

Through cultivation of the mainstream values of carbon neutrality and sustainable development, motivate residents’ social responsibilities for climate risks, change their consumption patterns, and enhance green living intentions; Foster new-generation climate citizens through schools and communities; Guide and guarantee the public and social organizations to participate in community green low-carbon affairs.

Strengthen Social Impact Assessment of Decarbonization and Green Development

Fully understand and assess welfare, obtained by different social groups, and possible adverse impacts in the progress of the “Double Carbon” goal; In urban green development, community green renewal, and green technology application, pay high attention to risks and vulnerability of females, the elderly, children, low-income groups, and vulnerable groups, and formulate corresponding strategies and mechanisms in aspects such as equity and inclusiveness.

Reinforce International Cooperation of Green Development and Renewal. Further carry out exchanges and cooperation of academic and specialized departments in green low-carbon development, actively learn the practical experience of developed countries on zero-carbon cities and communities, and impel international exchange of business enterprise sectors in green industries.

10.2 Policy Suggestions on Green Technologies in Community Renewal

10.2.1 Energy

Drive the market price mechanism of electricity demand-side response (load changes with resources). Expand the difference of electricity price at peak valley; provide subsidies for efficient energy utilization technologies and energy-efficient products, including household appliances with outstanding energy-saving effects.

Encourage the market development of stored energy, and stimulate V2G business and construction of more charging stations; encourage electricity sales through partition walls, release power of sale of renewable energy sources, activate the distributed generation market, and promote consumption of renewable energy sources.

10.2.2 Building

Formulate green building standards which are coincident and compatible in developed countries. Establish full life-cycle monitoring and assessment methods and governance systems for building design, construction, operation, and dismantlement, and promote full life-cycle management of green buildings.

Establish family/individual carbon-emission reduction mechanisms. Discounts of individual income tax deduction can be provided for families where energy consumption reaches an excellent standard; residents whose energy consumption greatly exceeds the standard can apply for government subsidies to make energy-saving renovations, and accept monitoring.

10.2.3 Mobility

Propel mobility low-carbon incentive policies. Include low-carbon mobility integral policies, subsidies for old vehicle elimination, award and discounts for low carbon vehicles and ships, etc.; Demonstration projects of mobility low carbon emission regions in pilot cities.

Optimize urban traffic structure. Develop dedicated roads for bikes, and guarantee continuity and networks of pedestrian ways; optimize rail network planning, and elevate the commuting coverage rate of rail traffic.

Improve mobility energy structure. Expedite promotion and replacement of New Energy Vehicles; Continuously reduce contamination and carbon-emissions intensity of newly-produced fuel vehicles, and establish full life-cycle carbon footprint assessments of the auto industry.

10.2.4 Municipal administration

Reform water price, and promote water conservation and efficient utilization through the regulatory mechanism of a ladder-like water price market; Achieve cooperative governance of water resources and water supply and discharge energy consumption in cities and communities; Achieve system efficiency promotion, energy consumption reduction, and carbon emissions reduction through cooperative smart management in terms of different qualities of multiple water resources, such as fresh water, rainwater, reused water, etc.

Optimize garbage classification supervision systems, formulate measures of reward and punishment, and enhance the quality of garbage classification; Optimize the charging system of garbage disposal, and promote decrement of garbage sources; Accelerate the establishment of recoverable material systems, introduce market mechanisms, stimulate participation of social capital, and promote increases in recoverable materials and decreases of other garbage terminal disposals.

10.2.5 Food

Optimize food and agricultural subsidy policies and establish a reliable food labeling system to promote sustainable food; increase public awareness of sustainable food systems and encourage food waste reduction and diet changes.

Promote urban agriculture and vertical farming to facilitate localized food production, distribution and green food demand under resource-constrained conditions and to improve the environment. Actively explore ways to reduce the economic costs of vertical farming.

ANNEX I: AN IN-DEPTH ANALYSIS ON THE SHARING ECONOMY AND THE CLIMATE?

Can Sharing help the climate?

With the spread of ICTs, particularly smartphones, the sharing economy has witnessed the birth of countless platforms and apps where people can share goods, such as cars or tools, skills and services, housing and accommodation or connect with each other to jointly use transportation opportunities. The question is: Does sharing help the environment and the climate? The scientific literature on this topic shows ambivalent results. On the one hand, sharing can contribute to avoiding or limiting consumption and decrease the need for the production of certain goods and therefore save resources and avoid carbon emissions. On the other hand, whether these potentials really enfold, depends on a multitude of different factors.

For example, via a sharing app someone could borrow a tool – let us say a power drill – that he or she does not frequently need from somebody else. This would make a new or initial purchase of that tool obsolete. Over its life cycle, a power drill produces approx. 28 kg of CO_2 equivalent with the usage of the tool accounting for only two percent of this amount (Skjelvik et al. 2017). If it is used more often, the emissions from its energy consumption may increase – depending on the energy mix used – but the emissions that would have been generated in the production phase of a new power drill are saved. But, the calculation is not that simple, because one would also need to ask how many times the tool would need to be shared in order to significantly reduce the power drill production and therefore significantly reduce the related CO_2 emission overall. Moreover, so-called rebound effects could occur that decrease, annul or even reverse the positive environmental effects. Rebounds happen in different ways, for example when the person that borrowed the power drill invests the money she or he saved to buy another, maybe even more carbon-intensive good.

Looking at these various considerations – which hold true in similar ways for other examples of sharing – it becomes clear, that in order to become a real solution for climate and environmental challenges, more needs to be done than just sharing. Its potentials can only be lifted if embedded in an overall transition towards more sustainable lifestyles and behaviors including sufficient consumption and more sustainable production modes.

ANNEX II: SMART CITY QUAYSIDE IN TORONTO

In 2017, the City of Toronto announced the development of a 49.000 m^2 large piece of land at its waterfront into a smart city district (Wilkens 2020). For that purpose, Toronto Waterfront, the agency in charge of the development of the area, partnered with the Alphabet-daughter Sidewalk Labs. What started with high expectations and much praise to create a smart and green residential and commercial area using data and latest technologies such as robots and underground waste disposal (Wakefield 2019), soon turned into a problematic case and drew much criticism from the local population.

In particular, concerns around the data governance approach of the smart city project became the centerpiece of public discontent and spurred the development of an activist group called “Block Sidewalk” (BlockSidewalk 2021). Researchers analyzing the case pointed to – among other omissions – an insufficient and ineffective public consultation processes, lack of digital expertise and legitimacy on the side of Toronto Waterfront as well as non-existent or inconsequential economic, social and ecological analysis of the technologies planned to be used for the project (Haggart 2020). Moreover, they argue that due to the weakly developed Canadian data governance framework, the land-development agency Waterfront Toronto, which is not publicly accountable, would have gained unprecedented power to shape future Canadian data regulation policies (Haggart, Tusikov 2020). The strong presence of Sidewalk Labs in Toronto could have furthermore put pressure on Canadian policy makers to regulate data rather in the interest of Google than in the interests of Canadian tech companies, let alone Canadian citizens (Haggart, Tusikov 2020).

After much debate, Sidewalk withdrew from the project in May 2020, naming economic uncertainties due to the COVID-19 pandemic as reason (Hawkins 2020). Researchers, however, see many lessons to be learned from the Quayside smart city project: Policy makers and urban developers need to take data issues and intellectual property rights seriously, develop data governance and policy frameworks independently and in advance to engaging with vendors and build own strong digital competencies. Furthermore, they need to rethink the role of platforms and engage citizens into the development of smart city concepts in order to avoid solutionist approaches to future city planning and to address the real needs and interests of urban residents (Haggart, Tusikov 2020).

Annex III: Calculation method of carbon emissions from community energy use

Carbon emissions from community energy use include carbon emissions from the three major energy sources consumed by the community: electricity, gas and water. The calculation formula is: Ee=E electricity + E gas + E water. Where: E electricity = Q electricity × f electricity; E gas = Q gas × f gas; E water = Q water × f water.

Qi represents the total amount of various types of energy use, fi represents the carbon emission factors of various types of energy use, f gas and f water are taken from the 2006 National Greenhouse Gas Inventory Guide and the Chinese Ministry of Science and Technology's Citizens' Energy Conservation and Emission Reduction Manual, respectively. f electricity is derived from the 2019 baseline emission factors of China's regional power grid , calculated using the emission factors of the regional power grid to which each city belongs.

Annex IV: Calculation method of carbon emissions from residential travel

Transportation carbon emissions are the carbon emissions per person per trip, which are affected by the travel distance and travel mode. The calculation formula is: $E_m = \sum_{i=1}^{40} \sum_k A_{k,i} \cdot L_{k,i} \cdot GHG_{k_i}$

$A_{k,i}$ refers to the traffic volume in year i of traffic mode k, and $L_{k,i}$refers to the distance traveled in year i of traffic mode k. Both can be obtained through residential travel surveys, and the travel distance can be obtained through data signaling data. GHG_{k_i} refers to the carbon emission factor in year i of traffic mode k. This parameter can be obtained based on reported literature studies, or by using the data measured in urban scenario years, or It can be converted by considering the new energy vehicle substitution scenario.

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