FUTURE CITIES
AND NEW ECONOMY CARBON NEUTRALITY
DRIVEN BY GREEN INNOVATIONS

UN HABITAT FOR A BETTER URBAN FUTURE

UN environment programme

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UN HABITAT
FOR A BETTER URBAN FUTURE

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Message from the Executive Director

Foreword by Ms. Maimunah Mohd Sharif, United Nations Under-Secretary General and Executive Director, UN-Habitat

According to the latest Intergovernmental Panel on Climate Change (IPCC) report, emissions of greenhouse gases from human activities are responsible for approximately 1.1°C of warming since 1850-1900. Over the next 20 years, global temperature is expected to reach or exceed 1.5°C above this baseline: the threshold, which the Paris Agreement aims to avoid. Indeed, even if the current policy frameworks of national governments are implemented in full, this would likely lead to temperature increases by 2100 of between 2.7 – 3.1 degrees – well above what is needed to manage our planet's environment effectively.

The human impacts of such global warming would be catastrophic, endangering the "safe climatic space" in which humans have flourished over the last few thousand years. It is a scenario that we cannot afford to realize.

Are we up to the challenge of cutting emissions by 45 percent by 2030 on 2010 levels, as the science demands? It is encouraging that countries representing more than 65 per cent of global carbon dioxide emissions and more than 70 percent of the world economy have made ambitious commitments to carbon neutrality in the last couple of years. City signatories to the Global Covenant of Mayors for Climate and Energy total over 10,735, and 700 + cities in 53 countries have joined the UN's Race to Zero Campaign are now committed to halve emissions by 2030 and reach net zero by 2050.

At the same time, delivering on these ambitious targets requires urgent and immediate action. The scale and pace of transformational change is unprecedented in human history: it will not be possible with business-as-usual approaches to achieve the necessary results. Radical innovation will be required, especially in urban areas, where more people on the planet now live.

Urban areas are responsible for 75 percent of global CO_2 emissions, predominantly from transport and buildings, and are home to 55 percent of the world's population. Without action in urban areas, national governments cannot meet their national climate and development commitments.

Luckily, we know what we need to do. Planning differently implies designing compact, connected, integrated cities and human settlements that optimize land, resources and energy use. We know that urban form and structure, and the building materials used, significantly affect greenhouse gas emissions - often for decades after completion. We are also aware that our ecosystems must be protected and expanded to absorb carbon dioxide and in order to ensure the wellbeing, health and safety of our communities.

These efforts to reduce greenhouse gases must go hand in hand with measures to reduce inequalities and manage rapid urbanization, because we know that without action on cities, attainment of the Sustainable Development Goals and its climate targets, will become impossible. Our experience has taught us that inclusive, broad-based participation that amplifies marginalized voices, and engages young people, is central to ensuring that no one gets left behind.

I am therefore pleased to introduce this publication, which provides a timely compilation of ideas, cases, innovative approaches, and practical strategies for achieving carbon neutrality in urban areas. Achieving climate neutrality will require innovation in all sectors of the economy and society – and this publication provides a range of evidence-based approaches and perspectives from economists, social scientists and ecologists, from research institutions, government agencies and intergovernmental organizations, from all over the world but with a focus on China and the Asia Pacific Region. Contributors to this publication provide a useful range of strategies, diverse approaches, thought provoking cases and best practices that take a new look at the opportunities and challenges posed by green innovations in global cities.

This publication does not attempt to comprehensively document or define specific pathways to achieving net zero emissions in cities. Instead, it intends to demonstrate the diversity of approaches and ideas that will be needed for us to collectively turn the needle towards climate neutrality in our urban areas, and, as a result, the world.

For UN-Habitat, strengthened climate action and improved urban environment and effective urban crisis prevention and response constitute two of our four strategic focus areas for the next several years. Working with all levels of governments, especially young people, civil society and the business community is essential in our global quest for a low carbon, climate resilient, inclusive and peaceful future. We look forward to continuing to engage with you on this vital and urgent journey.

Preface

Guo Huadong

Director of the International Research Center of Big Data for Sustainable Development Goals Member of the UN 10-Member Group to support the Technology Facilitation Mechanism for SDGs (2018-2021)

The core of *the 2030 Agenda for Sustainable Development* of the United Nations is to motivate its member states and stakeholders to take actions in order to produce and consume in a sustainable manner with the goal of achieving harmony between humans and nature, thus leading the world to embark on the path of sustainable development. According to recently released relevant reports by the UN agency on sustainable development, the global process of achieving the SDGs has been negatively affected by the COVID-19 pandemic, and progress in poverty eradication, zero hunger, reducing inequality, and climate action has been stagnating, some efforts even experiencing major setbacks. The average scores under evaluation of the realization of different SDGs in different regions of the world are also very different. For example, the average score of the high-income countries is about 1.53 times that of low-income countries.

Regardless if it's the imbalance between SDGs or the imbalance between regional sustainable developments, these are all hindrances to the comprehensive realization of SDGs. There's an urgent need to conduct in-depth research on the imbalance of realizing the SDGs and provide a more accurate and objective decision-making basis for the international community to formulate balanced development policies, thereby resolving the current crisis and transforming it into a turning point in reshaping the relationship between humans and nature. Thus it is a pressing matter to improve data tools and upgrade research methods. Big Earth Data is the big data in the field of earth science with spatial attributes, especially referring to the massive earth observation data generated by space technology, including data related to land, ocean, atmosphere, and human activities. These are massive, multi-source, and multi-temporal data that maintain a high level of integration.

Since 2018, the Chinese Academy of Sciences has conducted systematic research using the Big Earth Data to support the United Nations Sustainable Development Goals and achieved the following three types of achievements: Firstly, it has provided important scientific basis for sustainable development decision-making. We have released, for instance, *Big Earth Data in Support of the Sustainable Development Goals (SDGs)* for three consecutive years, assessing the progress of specific targets in the six SDGs and sharing practical cases to provide new impetus for the implementation of *The 2030 Agenda for Sustainable Development*; secondly, we have built a Sustainable Development Big Data Information Platform to support SDG indicator

monitoring and evaluation in terms of data sharing, online product on-demand production, online indicator calculation, and visual demonstration of results; thirdly, we have provided technical solutions for the realization of the SDGs. We attach great importance to research based on methodology and have introduced a series of methods, including models, analysis techniques, and comprehensive methods, and have formed a sustainable development big data solution that can be applied to other countries and regions in the world.

On September 6, 2021, on the occasion of the establishment of the International Research Center of Big Data for Sustainable Development Goals, Chinese President Xi Jinping and UN Secretary-General Guterres both emphasized, in their congratulatory letters and video speeches, the utilization of technological innovation to incentivize the scientific and technological community in realizing SDGs on a global scale. Comprehensive utilization of emerging technologies such as cloud computing, big data, artificial intelligence, 5G, blockchain, space technology, and network communication will provide scientific and technological support for China and the world's sustainable development. Both the UN's technology promotion mechanism and China's innovation-driven development will enrich our sustainable development "toolkit" with science, technology, and innovation to respond to global challenges and support the advancement of the agenda for sustainable development.

The special issue of "Future City and New Economy" this publication includes the ideas and practices of different countries and regions in the world in their efforts to promote the agenda for sustainable development and achieve carbon neutrality through green innovation. It also contains a wealth of cases, demonstrating how new technologies, models, and methods help advance sustainable development. Denmark, for example, is a pioneering country in the green and low-carbon transition, taking exporting green solutions as a national strategy to boost the agenda for sustainable development and provide new drivers for domestic economic growth. The country also carries out international cooperation by setting up innovation centers around the world; since 2017, the city of Chengdu, in southern China has been exploring the development of a new economy driven by digital technology using application scenarios to promote the landing and transformation of new technologies, industries, formats and models in urban space, while exploring the new path towards "The City of Parks" construction under the new wave of the industrial revolution.

Having been engaged in remote sensing and digital earth science for more than 40 years, I have personally observed numerous natural sceneries through remote sensing technology and Big Earth Data methods. I have also witnessed the rapid changes in many countries and regions. In particular via night-time light remote sensing images I could feel the prosperity that urbanization has brought to regions, but I have also witnessed the Gobi Desert disappearing with the construction of high-rise buildings. Moving ahead, I look forward to seeing the deep integration of the agenda for sustainable development and the process of urbanization from remote sensing images so as to create a prosperous scenario that highlights the harmonious coexistence between humans and nature. With this in mind, it requires more cities to actively explore the new paradigm of green development in joint collaboration of promoting the "Decade of Action" to achieve SDGs.

From the Editors

This second special issue of the publication series on Future Cities and New Economy aims to stress the important role of cities in tackling climate change and achieving carbon neutrality. In particular, the publication points out the need to invest in innovation to improve and broaden sets of solutions to achieve carbon neutrality.

Cities need to develop a pathway to achieve carbon neutrality by 2050 at the least, and set ambitious targets in terms of budgets and innovations. Also, robust policies, plans and partnerships with governments, businesses and communities are required in order to accelerate the delivery of cities carbon neutrality targets including mitigation targets and adaptation goals.

The publication has five sections. First section presents visions and challenges for cities under the carbon neutrality target. Second section discusses smart cities and digital infrastructure. Third section presents examples of some of the emerging technologies, applications, programs and measures including Nature-based Solution for ecosystems that are being implemented in different cities to reduce emissions and enhance carbon sinks. Fourth section discusses green financing and investments. The final sections constitute recommendations for different stakeholders including governments, private sector, and other non-state actors. Authors have shared concrete efforts, innovations and policies towards carbon neutral cities.

As highlighted in the publication, success of cities will mostly come from innovations, strong political will, partnerships with the private sector and communities, vast investments in green financing and clear determination to achieve ambitious targets.

We hope that you enjoy reading the special issue and it will stimulate new ideas for improvement and ways of achieving carbon neutrality. We welcome your feedback to strengthen our shared goal of enabling cities to play their roles in addressing some of the pressing global challenges.

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Mingxiao Zhao
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Climate change and cities: the imperative for action

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He has worked in the field of cities and climate change since 2010 and specialises in the nexus between climate change, urban development and governance. Steven supports UN-Habitat in its work to integrate climate change response into local and national decision-making, via research and writing, project management and implementation, strategic advisory services and facilitation. Steven has worked in South Africa and Kenya since 2012.

Carbon Neutrality is of Great Importance to China's Economy

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Xu Jintao is professor of economics and associate dean at National School of Development, Peking University. He is also the director of China Center for Energy and Development (CCED) of Peking University. His recent research range from assessing forest tenure reform in China, industrial pollution control policy, economic policy toward a low carbon economy, to transportation management in Beijing, etc. His publications appear on American Journal of Agricultural Economics (AJAE), Journal of Environmental Economics and Management (JEEM), Land Economics, World Development, Environment and Development Economics, and Ecological Economics. He obtained his bachelor of engineering degree in 1984 from Jilin University of Technology, master in forest economics in 1988 from Beijing Forestry University, and later MA in economics (1996) and Ph. D. in natural resource economics (1999), both from Virginia Tech.

Purposeful and transformative innovation for carbon neutral and inclusive urban futures

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Dr. Paris Hadfield is a Postdoctoral Research Fellow in Urban Innovation at the Melbourne Centre for Cities, the University of Melbourne, with expertise in urban climate policy and governance, energy system innovation, and financing sustainability in cities. Paris recently led an action research project with the Global Covenant of Mayors for Climate and Energy (GCoM) Research and Innovation Technical Working Group and Ironbark Sustainability investigating city research and innovation priorities at a regional scale, globally, as part of the Innovate4Cities initiative (funded by the European Climate Foundation for GCoM). Her PhD thesis (funded by the CRC for Low Carbon Living) examines urban experiments in renewable energy procurement, lending, and co-ownership in Australia, the UK, and Sweden to explain how financial systems change

generates local autonomy and inclusive social outcomes.

Achieving carbon neutrality: enabling and scaling up local urban community-led initiatives

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Dr. Hung Nguyen is a postdoctoral research scientist at Lamont Doherty Earth Observatory, Columbia University. His research aims to understand the variability and changes in the water cycle at multiple spatial and temporal scales, and apply such understanding to water resources management. Before academia, he was an engineer, running water treatment plants in Qatar and Singapore. Half way through his PhD, he realized that the key to the future lies in the past, and trees hold—in their rings—a treasure map that leads to that key. Since then, the weirdly wonderful world of tree rings has always fascinated him.

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Raphael Obonyo is a Public Policy Analyst, and widely published author around the world. He's served as a consultant with a number of international organisations including World Bank and United Nations. His experience spans government, private sector, and Non Governmental Organisations sectors, effectively bridging the gap between policy and community solutions. Mr Obonyo received a Masters in Public Policy from Duke University in the United States of America.

Can retail investors help to decarbonise cities?

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Comprehensive assessment of urban sustainability towards United Nations Sustainable Development Goals in Hainan, China : Based on the United Nations Sustainable Development Goals

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Pathway of achieving carbon neutrality: A city-level analysis in China's Xiong'an

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Xinyu Dou is a Ph. D. student in the Department of Earth System Science, Tsinghua University, under the supervision of Prof. Zhu Liu. She is particularly interested in carbon emission accounting, carbon neutralization, carbon emission map with high-resolution. Her work is now focusing on the realization of carbon neutralization at the regional level based on carbon data. She received her bachelor's degree in East China Normal University.

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Rui Guo joined Prof. Zhu Liu's group based in the Department of Earth System Science at Tsinghua University on the Shuimu Scholar Programme in 2019, after completing his PhD in earth sciences at University of Cambridge (2019), where he held the Cambridge International Scholarship to conduct research on the mechanism of radionuclide waste glass dissolution. His research is focused on assessment of various negative emission technologies related to atmospheric carbon dioxide sequestration. Special interests lie in the carbonation of natural and industrially silicates. He is also interested in research topics pertaining environmental implications and financial feasibility of nuclear power.

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Fighting plastic pollution with artificial intelligence and citizen science

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Ms. Kakuko Yoshida is Senior Programme Officer of the United Nations Environment Programme (UNEP), Asia and the Pacific Office and is Chief Technical Advisor to the project CounterMEASURE II for Plastic Free Rivers in Asia and the Pacific. With experience over 25 years, Kakuko has led programmes and projects on environmental assessment, air

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Prior to the UN, Kakuko worked for World Wide Fund for Nature in UK and Wildlife Club of Kenya. She holds BSc in Zoology/ Wildlife Conservation from Fort Valley State College in Georgia, USA, and MSc in Environmental Management from University of Stirling in Scotland, UK.

Urban Living Labs for the Green and Digital Transitionr

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Mingxiao Zhao is the vice president of Institution of New Economic Development, based in Chengdu. She ranks among 2020 Forbes China 30 Under 30 listees. She is the co-initiator and editor of the UNHABITAT 'Future Cities and the New Economy' publication series. She used to work for top international consulting agencies and has rich experiences in industrial transformation and urban consulting, including industrial planning, digital transformation, and policy suggestions. She is the co-founder of iNED. Now, she is committed to help local governments to adapt to the digital trend, upgrade business environment, build city brand and foster new growth drivers. She is actively engaged in researches and activities to encourage innovations for sustainable development agenda and worked with UN agencies, such as UN Habitat, UNDP and UN WOMEN.

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Four Dimensions for Systematic Promotion of Carbon Neutral Urban Development: lessons from Germany for Cities to consider

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After receiving her Diploma in Building Technology, Ms Pillen has worked in the field of building services engineering and building ecology, e.g.as technical superintendent for the Daimler-Chrysler project Potsdamer Platz as well as planning services taking into account energy-efficient technologies in various projects and as consultant to the Berlin Charlottenburg-Wilmersdorf borough office as to the increase of energy efficiency in municipal buildings.

Ms Pillen works at Deutsche Energie-Agentur GmbH (dena) – the German Energy Agency since 2003. As Deputy Head of Division Energy Efficient Buildings since 2011 and Head of International Cooperations since 2016 she is responsible for dena's model projects in Germany (2004 - 2009) and China (since 2009) for new construction and refurbishment as well as certification of highly efficient buildings, international project development and coordination in the field of energy-efficient building and Eco-Cities (China, Ukraine, Russia, Central Asia), and the development of building standards for residential and non-residential buildings with regard to legislation (Energy Saving Ordinance) and funding in Germany and China.

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Ms. YE works at the dena since 2013. As Team Leader for "International City Cooperation" she is responsible for development of conceptual ideas and strategies for projects in the field of "urban energy transition and climate protection", in particular for the structure of the projects and project contents (e.g.consulting services, energy concept development, public relations, dialogue measures, publications), development of benchmarks and recommendations for all energy-related fields of action in cities in China and internationally; development, testing and adaptation of innovative tools to support climate actions in regions and cities in China and internationally; initiation and support of model projects in pilot cities, analysis of market offerings; analysis of strengths, weaknesses and quality deficiencies in existing services, derivative of benchmarks and strategic action approaches and instruments; supervision the whole process of planning, executing and finalizing of projects, and development of strategic and operational concepts for project financing and design of the acquisition plans focusing on the stakeholder.

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Urban Planner Team Member, International City Cooperation

After receiving his Master of Urban and Regional Planning in Germany, Mr Zhang works at the dena since 2016 as team member of the sino-german cooperation program Eco-Cities in China. He is responsible for international projects in the field of energy-efficient construction and Eco-Cities, e.g.conceptualization and coordination of topics and ideas as well as the target planning with the project management in the area of ecological urban development and the implementation of energy and climate protection management in pilot cities in China.

Danish Experience And Innovation In Carbon Neutrality

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Green Bank Transformation Case for Carbon Neutrality

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Call for Action

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Previously, she worked at United Nations International Children's Emergency Fund(UNICEF) in New York Headquarters as a strategist and a Project Coordinator at United Nations Educational, Scientific and Cultural Organization (UNESCO) in Beirut, Lebanon. In addition, she had entrepreneurial experience in the field of Artificial Intelligence as the coconvener of China AI 30 Forum. She holds a B.A.in Finance and a M.S.in Social Enterprise of Administration with Columbia University in City of New York.

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Melissa is a human geographer urban specialist with over fifteen years of combined partnership, research, and development experience. She heads up the innovation unit

at UN-Habitat and has previously worked on land governance, urban planning, slum upgrading, urban legislation, policy and tool development, project management, country level and stakeholder engagement in the organization so has a strong overview of sustainable urbanization issues.She has worked at the country level and in intermediary cities and with a range of stakeholders from ministers to local chiefs.

At the innovation unit, she is leading an agenda to approach innovation in a holistic manner, incorporating both digital and non-digital innovations, and in strengthening the capacity of UN-Habitat and partners to use innovation as a tool for fostering sustainable urban development.

Projections suggest that cities have contributed to 75 percent of carbon emissions. To tackle climate change in the cities, technology is not our only concern. Addressing this problem also entails cost accounting and a balance in governing pattern - it requires our efforts in both economy and policy-making. As the world is still facing the macro environmental influence of fighting with the virus, pursuing carbon neutrality can also be considered a path towards sustainable development and green recovery. At the Leaders Summit on Climate on April 2021, the UN General Secretary Antonio Guterres said, "The trillions of dollars needed for COVID-19 recovery is money we are borrowing from future generations. We cannot use these resources to lock in policies that burden them with a mountain of debt on a broken planet." What does the goal of carbon neutrality really mean for economic development? Nobel Laureate in Economics William Nordhaus wrote this in his paper at the Copenhagen Consensus on Climate 2009: "Set forth a list of questions that should be factored in when formulating political and economic strategies on containing climate change: 1) How will climate change affect both economic and non-economic market activities; 2) Lower the cost 3) Map out the scale of emission reduction and the timing of implementing it while weighing profits and costs; 4) Asymmetric risk and that of irreversible damage; 5) Policy tools required for the above actions." Against such a background, we selected four articles that present visions and challenges in the journey toward carbon neutrality from the perspectives of global cities, the development of the economy, and policy innovation.

CHAPTER ONE:

VISIONS AND CHALLENGES FOR CITIES ASPIRING TO THE CARBON NEUTRALITY TARGET

Climate change and cities: the imperative for action

Steven Bland
UN-Habitat

1.The world we are in: carbon neutrality in the face of COVID-19

Since February 2020, the collective experience of the COVID-19 pandemic has dominated people's lives, their media and the political landscape. Repeated lockdowns have led to declining economic output, resulting in a significant reduction of 7% in global emissions in 2020, according to the Global Carbon Budget report (Friedlingstein *et al.*, 2020). The outlook for 2021 however, suggests that a rebound in global carbon emissions is almost certain, with the International Energy Agency (IEA) predicting the second largest annual increase in emissions ever, of 1.5 billion tonnes (IEA, 2021). This is second only to the post-recession economic rebound of the 2009 financial crisis which saw an increase of 1.5 billion tonnes in global CO_2 emissions from 2009 to 2010 (*IEA,2020*).

Back in 2009, the sharp increase was due to a 'brown not green' economic stimulus, where just 16% of stimulus spending was considered "green" (Barbier, 2009). Post COVID-19, the world economy is expected to dive into another recession deeper than that of 2009, yet current "green" stimulus spending falls short at just 12%, with a further 19% being channeled into sectors that may raise emissions or increase pollution (Vivid Economics, 2021). This is a missed opportunity. UNEP estimates that "a green pandemic recovery could cut up to 25 percent off predicted 2030 greenhouse gas emissions and bring the world that much closer to meeting its climate targets." The need for innovative approaches to bridge this gap between ambition and action towards carbon neutrality has never been clearer.

These innovations need to deliver not only rapid reductions in greenhouse gas emissions, but also a reduction in the socio-economic inequality that has arisen from the pandemic. The most impacted by the COVID -19 crisis have been the most vulnerable in society, such as those who are the least paid, are predominantly in the service sector, and have limited access to savings (IEA, 2020). In the Global South, vulnerabilities of food and health systems and local and national economies have intensified existing disaster risks (UN-Habitat, *2020*).

Response strategies such as lockdowns have had grave socio-economic impacts on livelihoods and gendered divisions of labour, while social distancing has been challenging to adhere to in overcrowded settlements, and access to services such as water, sanitation,

education and health have been affected. Policy makers must utilise lessons learnt from the last financial crisis to be more ambitious in leveraging green stimulus spending. This spending can incite wide ranging social benefits in the face of rising inequality as we aim for a "just" and low-carbon transition from the pandemic.. Fortunately, as UN-Habitat's Cities and Pandemics report points out – many of the required public health solutions in urban areas align with low-carbon, climate-resilient urban planning strategies: "compact, well planned cities combining residential and commercial functions with public spaces and affordable housing can improve public health, the local economy and the environment" (UN-Habitat, 2021).

2.Increasing urgency: the climate challenge intensifies

As emissions rebound once more on their decades-long upward trajectory, climate science is as unequivocal as ever on the link between human activities and accelerating climatic impacts. The Intergovernmental Panel on Climate Change (IPCC) released the first installment of its 6th Assessment Report in September 2021, which has been referred to as a "code red for humanity" (UN, 2021). The six years to 2020 are the warmest years on record, and the planet has already warmed by approximately 1 degree on pre-industrial levels (The reference period 1850–1900 is used to approximate "pre-industrial" global mean surface temperature (GMST)). Extreme weather events such as floods and heatwaves threaten lives, property and ecosystems, which in turn are predicted to induce the movement of climate refugees and increase the spread of disease.

The IPCC report warns of the small window for drastic emission reductions to stabilise the earth's surface warming temperatures to 1.5 degrees, as ambitiously committed to in the Paris Agreement. To avoid extreme climatic events, global greenhouse gas emissions will need to drop by half by 2030 compared to 2010 levels, and reach "net-zero" by 2050. If net-zero is reached by 2040, the chance of holding global warming to 1.5 degrees Celsius is considerably higher. The urgency of this challenge is reflected in the sudden influx of commitments in 2021 by countries ambitiously seeking to reach net zero emissions. As of May 2021, approximately 78% of global emissions are covered by net zero commitments. Despite this, in many countries, these ambitious long-term commitments are yet to filter through to concrete policy and finance actions. According to an analysis of the 113 new or updated Nationally Determined Contributions (NDCs) submitted to the UNFCCC as of July 2021, these parties would achieve a 12% reduction in emissions to 2030; well short of that required to avoid dangerous climate change impacts (UNFCCC, 2021). Indeed, if all NDCs of all parties to the Paris Agreement are included, assuming every country reaches its targets, global warming by the end of this century would reach 2.7 degrees above pre-industrial levels.

In the context of a closing window for concrete climate action, two relationships are worth highlighting: 1) between development and climate change and 2) between mitigation of

climate emissions and adaptation to climatic impacts:

The first is the relationship between development and climate change. The steadily advancing understanding of the economic costs related to inaction on climate change has helped drive policy agendas explicitly focused on the economic benefits of "green growth". Low carbon development in this context is predominantly framed around the competitive advantage that countries, regions and cities can attain by investing in jobs-generating industries and sectors such as renewable energy.

This discourse is rapidly gaining traction in the Global South, where a chasmic infrastructure deficit is leading the way for scaled up urban expansion, and the accompanying service-based infrastructure that this entails. One such example is in developing a green pathway to universal access to electricity. Achieving universal access to electricity by 2030 will require a 350 percent increase in the number of people in the least developed countries gaining access each year, compared with the last decade. This is a greater expansion in electricity generation than in the period 1990–2014, and in less time (UNCTAD, 2017). Ensuring this access is green should be a vital part of our zero carbon strategies and while grid electricity investments will be needed, decentralized electricity and energy provision in cities and urban areas will provide an important component of this effort. Considering that 24% of the world's urban population live in slums, finding ways to deliver basic services to the urban poor to uplift living standards, without massive increases in resource consumption, is a challenge requiring significant innovation and new thinking.

The urgent need for human development in the Global South often overshadows low emissions development, casting it as the smaller sibling to adaptation and resilience. Initially, this is understandable, given that the least developed countries account for just 3-6% of global emissions (Climate Analytics, 2017). Despite this, of the 20 countries that are responsible for 80% of global emissions, half of them are considered "developing". Emissions of these countries are growing rapidly and it is imperative that they find development routes that meet *both* their climate change and human development ambitions.

Fortunately, research, policy and practice are increasingly recognising that low and zero carbon ambitions make sense from a developmental perspective: they provide domestic economic opportunities, increase the resilience of the energy grid, and will increase trade and export competitiveness in an increasingly carbon-constrained world (Rahman, Mostofa and Huq, 2019). Cities in developing nations can lead the way in maximising the development benefits of climate action – including the health benefits from reduced air pollution. As the 1.5 degree Summary for Urban Policymakers highlights: "There are sizable co-benefits from emission reductions, including higher productivity and job creation, better health and life expectancy for citizens, improved air quality, more walkable and livable cities, and lower vulnerability and greater resilience to extreme events, including fires, floods, and hurricanes" (IPCC, 2018).

The second is the relationship between mitigation of climate emissions and adaptation

to climatic impacts. This relationship is sometimes fraught – with different practitioners advocating for heightened financial investments in one or the other. The reality is that an integrated approach of both mitigation and adaptation is needed. Whilst some warming is now inevitable and adapting to it will require a significant upscaling of investment, this is not an argument in favour of giving up the fight on mitigation. As the IPCC (2018) pointed out in their landmark report on limiting warming to 1.5 degrees: "Every extra bit of warming matters, especially since warming of 1.5 C or higher increases the risk associated with long lasting or irreversible changes".

Rather than seeing mitigation and adaptation as binary choices, approaches and solutions that support the delivery of both must be prioritised. Prof Dan Friess's contribution to this publication in chapter three on the mitigation potential of urban coastal ecosystems highlights this approach exactly, where coastal ecosystems can be seen as wise investments for both water health, flood impact reduction and potentially also climate mitigation efforts. In general, discussions and programmes on climate innovation tend to focus on climate mitigation - which lends itself to a discussion about technologies and finance. Nonetheless, the crucial need for innovative approaches, especially in relation to financing for climate adaptation, is equally important. Therefore, when carbon neutrality is discussed in the context of cities (including in this publication), there must be insight into holistic and integrated approaches that recognise the interconnection between the prioritised objective of reducing emissions, and the need to build resilience and wider sustainability objectives. It is this pragmatic integration of ambitions that is most likely to succeed.

3.Text box/insert: definition of key terms

There are a number of different terms used to describe efforts to achieving the Paris Agreement's goals of global net zero emissions by 2050.

Net Zero emissions: When emissions of greenhouse gases to the atmosphere *originating in human activity* are balanced by *human originated removals* over a specified period (IPCC, 2018)[i]. This term originated from climate science and has a global focus.

Climate neutrality: The term is often used interchangeably with net zero emissions. It implies the reduction of emissions and subsequent offsetting of residual emissions to achieve a neutral, or net zero, state. The term is more often used at smaller scales: for example by companies, institutions or cities.

Zero carbon emissions and carbon neutrality: More often, these terms are used in reference to one specific greenhouse gas: carbon dioxide. This is a smaller scope of focus than net zero or climate neutrality, not taking into account other greenhouse gas emissions such as methane.

Net zero and climate neutrality approaches therefore go beyond low-carbon development by combining aggressive reductions in emissions with measures to offset/compensate for residual emissions that cannot be eliminated, through the purchase of carbon credits or

through the implementation of negative emissions technologies such direct capture of CO_2 from ambient air - Direct air carbon capture and storage (DACS), and bioenergy with carbon capture (C40, 2019)

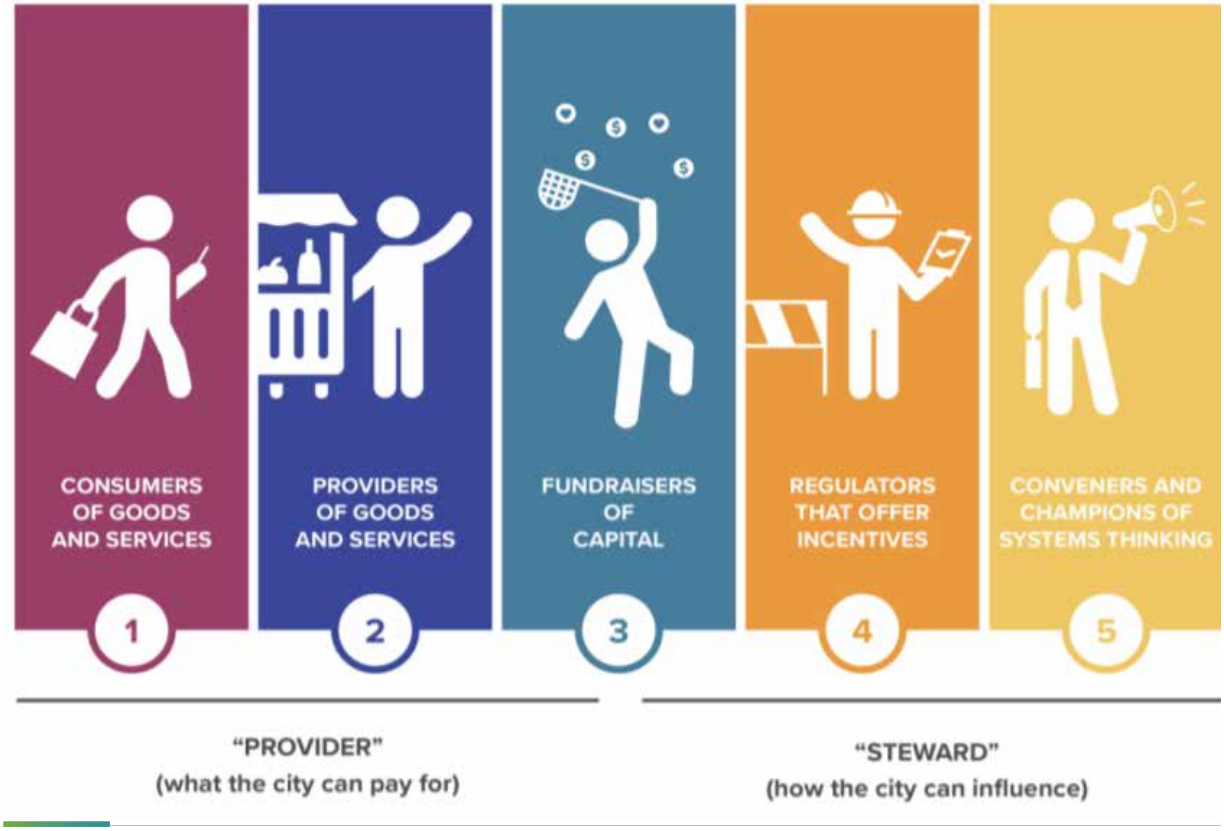
4.Cities at the crucible of climate innovation

Cities consume over two-thirds of the world's energy and are responsible for more than 70% of global carbon dioxide emissions. Buildings alone account for 32% of global energy consumption (IEA, 2016c). The rapid pace of urbanisation around the world is only set to increase this further: "for the next 3 decades, nearly seventy million residents will move to urban areas every year. The majority of these new residents will live in small- to medium sized cities in the developing world." (Bazaz et al, 2018). Efforts to decarbonise the world's cities will need to both rapidly reduce emissions in high emitting countries while ensuring that rapidly expanding urban areas in the global south, and their populations, especially the urban poor, get access to services and infrastructure needed to meet the SDGs, in as low-carbon a manner as possible.

Despite this, cities, through their growing capital and diversity of growing populations, are also incubators of innovation. These opportunities for innovation can then be scaled up to national commitments to climate action through urban policy, which in turn could stimulate more financial support and improved capacity for the transfer of innovative technologies and approaches. The potential of urban areas to be at the forefront of efforts to tackle climate change is being increasingly recognised by the international community and by investors.

In its flagship 1.5 degrees report in 2018 the IPCC identified four system transitions that would be needed to restrict global warming to 1.5 degrees. The report argued that meeting such a target was technically possible but unprecedented in human history in terms of scale and speed. Those four transitions are:

1. Urban and infrastructure
2. Energy: including the global transition to 70-85% renewable electricity by 2050
3. Land-use: including the sustainable intensification of agriculture, a reduction in demand for meat, and reduction in food waste, reduced rates of deforestation and reforestation.
4. Industry: currently responsible for one third of global final energy use; requires significant reduction of energy demand coupled with the introduction of circular economy approaches.
5. The urban transformation requires rapid shifts in 6 key areas:
6. Buildings: Responsible for over a third of global energy consumption. New buildings must be built fossil-free and near zero energy by 2020 (yes, 2020)
7. Green urban infrastructure and ecosystem services: including integrating trees, parks and green roofs into urban planning
8. Urban energy systems: including decoupling urban growth from increases in fossil-fuel powered energy, and expanding access to clean energy especially in informal settlements
9. Sustainable urban water and environmental services: including measures to reduce impervious surfaces and associated runoff



© **Source: World Bank (2021)**

10. Transport and urban planning: The transport sector must reduce its final energy use by 30% by widespread adoption of low-carbon fuels. UN-Habitat consistently promotes the idea that well designed, compact, walkable cities with good public transport greatly reduce per capita carbon emissions.

11. Climate resilient land-use: including infrastructure and buildings investments that reduce risk; through integrated adaptation planning and urban planning.

Achieving the kinds of rapid and far-reaching transformations in each of these six areas will rely not only on technological and financial innovations that help bring down the costs of climate-friendly solutions, but also new approaches to mainstreaming climate action into development and financial planning. The World Bank's State of urban climate finance report, published in 2021, highlights the massive gap between climate finance needs in cities, and actual levels of investment. Despite needs for investments of trillions per year, annual urban climate finance in 2017-2018 totalled just $384 billion (World Bank, 2021a).

Overcoming this gap requires financial and governance innovations that enable the incorporation of climate change data, criteria and conditions into government budgets, financial decision making and investments. While easy in theory, in practice climate budget mainstreaming has been hard to achieve. As the IADB comment: *"The idea of "mainstreaming" implies a shift from financing climate activities in incremental ways, to making climate change – both in terms of opportunities and risks – a core consideration and a "lens" through which institutions deploy capital."* In the second part of the World Bank report on the enabling conditions for urban climate finance, the authors highlight the four levels of local government planning that climate considerations need to

be mainstreamed and embedded into: strategic planning, spatial planning, capital investment planning and budgetary planning. Doing so will require local governments to engage in five different enabling roles as identified in the report:

Fulfilling each of these five roles will involve, for any individual local government, varying degrees of experimentation and innovation, as well as pushing up against established legal and policy frameworks that might hinder their mandate to raise and spend revenue in ways that the climate challenge might demand.

Therefore, financial innovation often relies on strong and effective governance systems and practices through multilevel governance. Multi-level governance has been defined as the *"structural and institutional setting in which different levels of government distribute roles and responsibilities, coordinate and cooperate on climate action; as well as the specific instruments that are implemented at different levels of government to support and implement local climate action."* (GIZ 2020). Only by supporting systems of collaboration between and within national and local government, and with other crucial stakeholders, can we ensure climate change is tackled successfully while meeting development goals. The Urban-Low Emission Development Strategies (Urban-LEDS) project published a schematic summarising the important components of multi-level governance for climate change action, available here.

Crucially, the diagram includes both vertical and horizontal integration: vertical integration between global-national and local climate relevant actors and departments, but also the integration and mainstreaming of climate change into sectoral and line Ministries of government, and their relationships with local government. Multi-level governance includes a focus on a number of important enabling conditions, including: a) Capacity, b) Fiscal decentralization, c) Public participation, d) Mandate for climate change-related areas, e) Supportive legal frameworks, f) Data collection and sharing, g) Political will.

What has been achieved through this focus on climate action in cities?

In recent years, the pace and scale of urban climate ambition has increased dramatically. In the last few years, 2078 sub-national jurisdictions and local governments have declared a climate emergency. This represents renewed commitment demonstrated ICLEI - Local Governments for Sustainability's carbon Climate Registry of sub-national government action on climate change. This self-reported database includes 1153 individual entities who have between them reported over 7000 individual mitigation and adaptation actions to date. Many cities are also committing to go further, faster and reduce their "fair share" of emissions by developing 1.5 degree compatible climate action plans. An analysis by the C40 cities group of 54 of their members' new climate action plans showed that, if implemented in full, these plans would prevent at least 1.9 gigatonnes of GHG emissions from being released into the atmosphere between 2020 and 2030, equivalent to half the combined annual emissions of the European Union's 27 member states.

Despite the efforts of these leading cities, there remains a large gap between the scale

of action required in cities and the capacity to deliver it. For example, according to Carbon Disclosure Project (CDP) analysis, 43% of global cities do not have adaptation plans despite 93% of the 812 disclosing cities report that they are at risk from climate change. Many local governments lack the capacity to develop key climate metrics that can support their decision making, such as greenhouse gas inventory or climate vulnerability assessments, or to develop and package projects in order to attract investments.

Despite proclamations on the need for systems transformations by the IPCC and others, outside of the energy sector, these transformations are harder to identify. Therefore, innovation in the realms of technology, finance, policy, governance and society are still sorely needed and support is needed to assist urban actors in delivering these. The final section looks briefly at some key principles and approaches to innovative climate action in cities.

5.Principles and approaches to innovative climate action in cities

Achieving climate neutrality in any individual city will require extraordinary efforts involving all segments of society, government and business. Local governments can play a crucial role in enabling climate innovation in urban areas. In the final section we suggest some important principles for taking an innovation-led approach to tackling climate change in cities.

Principle 1: Technology plus +

There is no doubt that the technological innovations of the fourth industrial revolution are driving widespread social change, and have widespread applicability in both the global north and global south. Frontier technologies in the area of digitisation and big data have the potential to significantly improve urban development and climate outcomes; for example the adoption of Artificial Intelligence to support air pollution reduction or waste optimisation, or digital twinning for disaster risk planning (ITU, 2020).

However, a focus on the technological solutions themselves hides the importance of wider social and governmental processes in determining the deployment and success of new technologies. As Bill Gates puts it:

"In energy, software, and just about every other pursuit, it's a mistake to think of innovation only in the strict, technological sense. Innovation is not just a matter of inventing a new machine or some new process; it's also coming up with new approaches to business models, supply chains, markets, and [government] policies that will help new inventions come to life and reach a global scale. Innovation is both new devices and new ways of doing things." (Gates. 2021)

As such, innovation is as much about process as it is about material science or manufacturing. Indeed, the Coalition for Urban Transitions has calculated that greenhouse gas emissions from cities can be reduced by almost 90% by 2050 using technically feasible, widely available mitigation measures (CUT, 2019). Despite the constant hope for a silver bullet solution, it is not necessarily the quest

for new technology that will determine the success of our collective climate goals, but rather the ability to implement existing technologies in ways that are fair and leave no one and no place behind. In her contribution to this publication, Paris Hadfield takes this argument further by arguing for "purposeful innovation". Similar to the mission-driven innovation approach now championed by the European Union, this method suggests that rather than innovation being framed as a means to achieving economic growth, innovation must be framed as a means to achieving social and ecological goods, and in overcoming the "grand social challenges" of our time.

Innovation theory and practice is replete with characterisations, descriptions and typologies of innovation. UN-Habitat's definition of innovation in the context of urban development highlights a similar technology+ approach. UN-Habitat (2020) defines innovation in five ways:

1. New ways of thinking, approaching a problem or a process from a new angle or perspective
2. Incremental and a process evolving over time to deliver new and improved processes and outcomes
3. Disruptive, radical change from what has been done before
4. Technology driven, tapping into frontier or cutting-edge technological solutions
5. Related to non-technological approaches such as a new way of engaging people or integrating sectors in a planning process which have not been used in that context before

Through the intensive process of defining innovation comes an opportunity to create a roadmap for implementation. The Organisation for Economic Cooperation and Development (OECD, 2019) has created a typology of local government innovation which highlights the multiple ways in which they can adopt innovative approaches that go beyond a sole focus on technology. This typology of innovation is included below, exemplified by cases from urban climate action around the world. The intention is to give a flavour of the variety of ways in which urban climate innovations can manifest:

Innovation approach	Urban climate application
Taking risks or testing new idea	In Cape Town, South Africa, an Industrial Symbiosis Programme connects companies with unused or residual resources such as materials, energy, water, assets, logistics and expertise. This reduces waste, saves C02 and saves companies costs
Data-driven analytics/public data management	Google's Environmental Impact Explorer uses exclusive data sources to cost-effectively and accurately estimate greenhouse gas emissions in the building and transportation sectors, as well as renewable energy potential
Engaging residents in new ways	In Melbourne, Australia, the Urban Forest Visual has mapped every public tree in the city, including the ability for citizens to email messages to individual trees to spark a connection with urban nature. In the Urban-LEDS project in South Africa, cartoons and drama were used to communicate to residents the results of a scenario planning exercise conducted by the municipality to imagine a low-carbon future by 2030. Mapeando is an app developed in Rio de Janeiro, Brazil, in which citizens place their demands (e.g location of bike lanes) on an online map- these are then compiled into a report that shows what people would like.
Developing new solutions based on digital technologies	Chosica, Peru, has adopted a digital early warning system which analyses photos and data from sensors and cameras installed on houses to track rainfall data and soil saturation levels.
Organizational change within the municipality	The City of Tshwane, S.Africa, established the City Sustainability Unit in 2013, located within the Office of the Executive Mayor. The unit's role is to coordinate between departments and assist in facilitating access to external funding for green economy projects, including municipal building efficiency. The City of Cape Town, South Africa, developed an Environmental Education, Training and Awareness Strategy for its staff to support the delivery of energy efficiency targets in municipal-owned buildings
Human-centered design	In Austin, Texas, human centred design based research discovered space as the major limitation to why residents in apartments were not using recycling facilities; leading to the introduction of new stackable bins
Rethinking approach to financing partnerships	The City of Toronto, Canada is piloting a circular economy procurement framework, including engaging with key suppliers to support them to make the changes needed in order to meet the new criteria

© **Source: The author, based on typology of OECD (2019)**

Principle 2: People centred approaches

The urban poor are responsible for a miniscule % of the world's historical and current carbon emissions, and are most at risk from the anticipated impacts of climate change. Therefore, it is important that climate action, digital technologies, and decarbonization efforts do not run the risk of harming, rather than helping, efforts towards justice and equity. Innovation efforts, via their focus on stimulating commercially viable technological solutions, can lose sight of wider social justice imperatives.

UN-Habitat has introduced the 'people-centered smart cities' approach, which aims to show how smart cities can be an inclusive force for good, if implemented with a firm commitment to improving people's lives and building city systems that truly serve their communities. Through its motto of leaving no-one and no place behind, this people-centred approach is rooted in UN-Habitat's work in many sectors, including climate change.

Innovation actions must be developed under participatory and inclusive structures, and deliver co-benefits such as improving health outcomes, promoting economic development, delivering jobs and addressing gender and racial inequities. In specific areas, such as energy, buildings, food or mobility, "triple dividend" actions can be taken that reduce the ecological footprint while simultaneously creating employment opportunities for people with low levels of qualification and facilitating access to goods and services essential to the enjoyment of human rights. This must be the acid test for any urban climate actions and innovations.

Principle 3: Systems-based approaches

Systems innovations are *"directed to redesigning entire systems of practices and provisions, instead of individual products or processes"* (Sterrenberg et al, 2013:9). Understandings of systems innovation highlight the importance of non-technology processes such as institutions and culture, of path dependency and lock-in, and of the primacy of uncertainty and complexity. Systems approaches to innovation also stress process as well as outcome: including multiple iterations of learning and reflection to improve understanding and to "try again" at achieving the transformational change that is so sorely needed. As one of the early systems thinkers, Donella Meadows, put it:

"The world is a complex, interconnected finite, ecological-social-psychological-economic system. We treat it as if it were not, as it were divisible, separable, simple and infinite. Our persistent, intractable, global problems arise directly from this mismatch" (Meadows, 2010).

Climate change is one of those seemingly intractable meta-systems problems. Embedded within it are a whole sub-set of human systems that need to be fundamentally redesigned if we are to achieve both zero carbon and climate resilient development: the energy system, the transport system, our urban systems. Despite years of negotiations, investments and action plans, global emissions continue to rise year on year. Could insights from systems thinking help us to bridge the implementation gap we appear to have between our collective climate commitments/ambitions, and the outcomes being achieved? Research by Climate-KIC highlighted the importance

of governance innovation in achieving systems-level changes that support climate action. Innovations are needed in order to:

1. Overcome siloed working in government
2. Move towards a focus on dealing with root-cause/underlying issues, not just tinkering with existing policy
3. Move beyond technocratic models of policy-making processes dominated towards incorporating insights from behavioural studies and systems thinking
4. Break down resistance to radical governance innovations that invert existing power structures or ways of doing things (eg citizens climate assemblies)

A useful methodological insight of systems theory has been the multi-level perspective. It highlights the fact that transformations and transitions can be understood as an interaction between activities taking place at three different levels of society:

1. At the macro-level: landscapes include paradigms of understanding about the world, and long-term trends, dominated by slow changes
2. At the Meso-level: regimes that include dominant structures, cultures, norms and practices
3. At the micro-level: niches containing innovative ideas, projects and technologies(Markard and Truffer 2008)

For practitioners, these insights from academia can assist the design of policy-making and innovation processes that recognise the potential levels of change, where to focus efforts, and who to engage to achieve them. They can help to move beyond a project approach, towards an engagement with and encouragement of multiple actors across the specific system that a local government or urban practitioner is trying to change (e.g mobility or household energy use). For example, the “OneLess” initiative - which targets a significant reduction in the use of single-use plastic water bottles in London - used the multi-level perspective as a methodology to design the systems-level interventions it would adopt. By identifying the slowly shifting narrative and social values around plastic use at the *macro-level*, the increasing willingness to change and act by organisations and citizens in the *regime leve*l, and emerging alternatives to plastic bottles at the *niche margins*, the initiative developed a system map of 11 potential leverage points that could be pressed to being about accelerated change.

The One Less Initiative, now 6 years old, has brought together over 94 organisations committed to its goals, prevented the sale of 5.6m single-use plastic water bottles and seen 829,000 bottles refilled at 29 newly constructed drinking fountains.

Principle 4: Collaborative process innovation

Moving beyond a narrow focus on technologies, building in a people-centred and socially just mentality, and moving beyond pilots to systems based approaches all require a single intervention: innovations in how policy-making and implementation takes place. Process innovation involves the exploration of new ways of defining challenges and finding possible solutions, bringing stakeholders and citizens into processes of co-creation, and changing procurement systems to stimulate local innovation by companies and entrepreneurs.

Collaborative process work in the first instance takes place within local governments as a tool to overcome siloed decision making. Doing so requires grappling with long-standing barriers to innovation in the public sector; such as well-intentioned procurement rules to prevent financial mismanagement, and the predominance of risk averse cultures, partly due to the risk of civic litigation.

At the same time, the complexity of urban governance, and the systemic nature of the climate change challenge, requires working collaboratively with citizens, civil society and businesses in the policy design and implementation process. When this approach is targeted at the local start-up community, the German Cooperation for International Cooperation (GIZ) calls it *collaborative innovation for climate change:*

"Collaborative innovation matches the knowledge, networks and resources of local governments and cities with the entrepreneurial ideas and approaches of innovation ecosystems — to drive climate mitigation and adaptation." (GIZ, 2019)

By both using their purchasing power to encourage new ideas to market, and investing in start-ups and entrepreneurs working on climate-friendly solutions in critical urban sectors such as transport, planning and wate, local governments can support an innovation ecosystem that will support the delivery of their climate goals. This is an integral part of the systems innovation story, which encourages local governments to enable stakeholders to help deliver on city-wide climate targets.

These approaches form a key pillar of the EU's Mission for Climate Neutral and Smart Cities (EU, 2020). In this framework, the key drivers towards systems innovation are; (i) collaborative governance through process innovation that enable the co-creation of ideas and policies with local citizens, and (ii) the movement towards more integrated, silo-breaking policy-making and delivery. There is also a continuous development of more tools and methodologies that local governments can use to achieve such an approach. Process innovation takes many forms, as Nesta's (2019) *compendium of innovation methods* demonstrates. Accelerator programmes, which support start-ups and small businesses to quickly upscale their impact, can be used alongside public and social innovation labs to deep dive on specific challenges, and prototype ideas and solutions. Futures based approaches encompass a suite of methods that look to emerging trends in order to build pictures of possible futures that can help improve decision-making today. UN-Habitat has adopted one such futures methodology in its work to promote the integration of urban planning into data centre communities.

Scenario planning is used to devise possible futures for communities seeing large scale investments in the IT and data centre industries, in order to help stimulate partnership based, proactive urban planning that can manage growth while delivering on sustainability goals.

The value of process innovation is its applicability in diverse contexts. UN-Habitat is increasingly working to integrate such innovations into the ways in which it works. The creation of a brand new Innovation Unit in

2019 was an important milestone. A flagship project that uses insights from innovation theory and design is found within UN-Habitat's partnership with Viable Cities and Nesta Challenges through the Climate Smart Cities Challenge. This project entails working with the cities of Bristol (UK), Bogota (Colombia), Curitiba (Brazil) and Makindye Ssabagabo (Uganda), to support them through a challenge design process that turns the normal solution-finding process on its head. By putting their climate challenges, (in the housing, mobility, and neighbourhood development sectors) out to the market, the intention is to open up the diversity and scope of potential solutions, crowd-sourced from innovators that apply to support the city in solving their climate challenge. These innovators will then be supported to test and refine their solutions in city-wide systems demonstrations. These demonstrations will borrow learning from systems innovation theory, by testing combinations of solutions with policy, legal and governance innovations to boldly attempt to build a viable model for a systems-wide implementation of the solutions being tested.

Moving beyond technology, taking a people-centred and systems-based approach, and implementing collaborative process innovation: all four principles can act as guiding posts for local governments and their partners in adopting innovative climate actions. The climate clarion call continues to ask for rapid and transformative action; each year the sense of urgency grows. Therefore, as more and more cities put in place the foundational and agenda-setting steps of city climate action planning, and subsequently move onto the challenging task of implementation, the need for innovative approaches is only set to grow.

6.This publication's contribution

Given that emissions and risks emerge from every aspect of human life in cities – reducing both of them requires an equally diverse collection of solutions and approaches. The publication Future City and New Economy: Carbon Neutrality Driven by Green Innovations explores and discusses innovative approaches and policy responses at the local government level, and focuses on different dimensions including finance, governance, smart cities and more, from academics, experts and practitioners.

This report does not offer a ready-made blueprint for how net zero emissions in cities can be achieved. Instead it provides an assemblage of insights and examples of how multiple sectors and actors in society can take innovative approaches to reduce emissions and increase climate resilience. Simultaneously, the publication is part of the efforts to encourage cities to play an active role and help countries deliver on their national and international climate commitments and contributions, in order to meet the targets of the Paris Agreement.

Chapter one discusses visions and challenges for cities under the carbon neutrality target. Professor Jintao Xu, the director of the Environment and Energy Research Center at Peking University, explores the relationship between carbon-neutral goal and sustainable

economic growth. Xu argues that economic policies in China should be the primary tool for carbon neutrality and carbon emission reduction. Dr. Paris Hadfield, an Urban Research Scientist in Urban Innovation at the University of Melbourne's Centre for Cities, explains why implementation of city climate strategies require institutional innovation through experimentation – not only to enable the deployment of existing technologies, through which significant emission reductions are possible, but to establish mechanisms for collective problem-solving and alternative measures of the value of innovation.

Chapter two looks at smart cities and digital infrastructure. Dr. Nataliya Tkachenko, a data scientist at the Oxford Sustainable Finance Programme, argues that getting metropolitan areas to environmentally neutral states requires substantial funding injections from private finance actors. Dr. Tkachenko, discusses how, given the increasing growth of interest in infrastructure from another type of private finance actor - retail investors - they employ Google Trends data signals in order to demonstrate how these emerging investment preferences can help to shape urban decarbonisation strategies and account for the social agendas on the global scale.

Huadong Guo and co-authors present a case for comprehensive assessment of sustainable development goals, and take Hainan Province in China as the research area, using earth observations, statistics, and other public sources to monitor and comprehensively evaluate Sustainable Development Goals (SDGs) indicators to better support the realization of the carbon neutral target. Zhu Liu and co-authors, provide a model city-level carbon neutrality analysis framework and construction path. Taking Xiong'an New Area as an example, the authors identify the range and boundary of carbon emission assessment in various sectors. Combining statistical yearbook data, nightlight data, and arbon monitor technology (a near-real-time daily gridded fossil CO_2 emission dataset), then calculates the city's carbon emissions and further analyzes the *status quo* and characteristics of key emitting sectors. The article provides guidance for the emission path and technology path of the Xiong'an New Area to achieve carbon neutrality, and further improve the supporting policy system of the demonstration project. In the last article, Kakuko Nagatani-Yoshida of the United Nations Environment Programme, discusses the fight against plastic pollution through artificial intelligence and citizen science. Ridwan argues that without more data and scientific insight about how the plastic becomes plastic pollution in waterways, rivers, wetlands, and then in the coastlines and ocean, there will always be a risk of policies being ad-hoc resulting in limited positive outcomes or even with potential negative consequences.

Chapter three explores emerging technologies and applications scenarios in cities. Nicole Pillen, Ang Yeh and Hui Zhang from the German Energy Agency, use examples, lessons and experience from Germany to discuss the need and importance of transformative action to achieve overall climate goal. In particular, the authors argue that promoting carbon neutral development requires systematic programs, and the urgency of climate change requires that these programs are implemented at scale as soon as possible.

In another article, Mingxiao Zhao and Tao Zhan from Institution of New Economic Development (iNED) makes a case for urban living labs' collaborative approach required to accelerate the realization of dual goals of carbon neutrality and economic growth. Heidi Yujie Su, Martin Hoxer and Morten Kruse from the Danish Innovation Centre share danish experience with carbon neutrality. In particular, the authors highlight Denmark's remarkable efforts in reducing greenhouse gas emission and increasing renewable energy usage since the 1990s, and carbon neutrality is prioritized.

Chapter four discusses green finance innovations in cities. Yolanda Zu and multiple authors discuss the green bank transformation cases for carbon neutrality. The article explains International Finance Corporation's (IFC) recently launched initiative, Alliance for Green Commercial banks as a response to the growing demand from financial sector clients and international partners for a more standardized approach to ensure the credibility of green banking. In the final article, Zeng Hui from Tsinghua University, discusses the importance of the financial data factor market and how it can help China achieve its market goals. While acknowledging the challenges of constructing a financial data factor market in China, the author gives a series of policy considerations required to achieve carbon neutrality, high quality and economic development.

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Carbon neutrality is of great importance to China's economy

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Abstract

On the basis of China's current development stage and practical constraints, this article demonstrates that the carbon neutral commitment not only represents China's responsibility toward the global community but also drives China's economical transformation, industrial upgrading, and institutional adjustments. Discussing pathway to carbon peak and neutrality in China provides the global community with insights into China's transition model as the world's largest carbon emitter. From the perspective of China as a developing country, the review of the relationship between its economic development model and the response to climate change is of considerable significance to countries and regions in the transition to green economy and the search for carbon neutrality development opportunities under the SDGs.

The 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (the Paris Climate Conference) held in 2015 had two main outcomes. One is that the participating countries in the conference generally agreed to cap the increase in the global average temperature at 2 or ideally 1.5 degrees Celsius by the end of this century. The second is that the major emitters have all made voluntary commitments of less emission.

This is a milestone achievement of the climate negotiations, but there also remained some disappointments. If the voluntary emission reduction commitments of the major emitters stay at the 2015 level, it will be impossible to cap the rise of the global average temperature at less than 2 or 1.5 degrees by the end of this century. Remorsefully, it is very likely that the temperature will increase 3-6 degrees Celsius.

Therefore, the Paris Conference of the Parties proposed a plan: by the year 2020, the major emitters should review the temperature control goal of 2 or 1.5 degrees Celsius, and revise and greatly improve their own voluntary emission reduction commitments in order to actually achieve the temperature control target.

China is the world's largest emitter, with annual emissions taking up to 30% of the globe. If China does not take active initiatives, the global climate action goals will not be met. Thus, if we want to maintain the results of the Paris Conference of Parties, and for all mankind to curb global climate change, China must play a pivotal role, or say, a leading one.

In 2020, President Xi made two commitments

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at the United Nations General Assembly: the first is that China will strive to achieve the peak of carbon emissions by 2030; the second is that China proposes a ultimate goal, that is, to achieve carbon neutrality by 2060. Carbon neutrality means that with substantial emissions reductions, the remaining emissions can be completely absorbed by the ecosystem.

These are groundbreaking commitments.

But is Chinese society ready? I realize there's still a long way to go. The various schemes and road maps previously put forward by energy and climate experts are conservative in comparison with the commitments carbon peak and carbon neutrality. Therefore, the Chinese society, especially the core sectors such as energy and climate ones, will be under unprecedented pressure. In order to peak the emissions and neutralize carbon, China's growth model must go through a very drastic change. These two goals will form a mechanism for reverse stimulation.

The carbon emission peak and carbon neutrality goals have appeared multiple times in the 14th Five-Year Plan and are also prominently reflected in the Report on the Work of the Government. On March 15, 2021, President Xi attended the meeting of Central Finance and Economics Commission and put forward specific requirements for carbon peak and neutrality goals.

The Chinese government and society must act conjointly to achieve these two goals. To realize the transformation of the economic growth model, there must be great changes in the economic structure.

1.Grand Changes in Energy Structure

At the Central Committee of Finance and Economics, President Xi called it a great goal to build an energy system primarily consisting with renewable energy during the 14th Five-Year Plan period.

About four or five years ago, at an energy sector meeting, I asked those experts that since many European countries have proposed to completely replace fossil energy with renewable energy by the middle of this century, would it be possible for China to do so as well? Their answer is almost negative due to China's heavy dependence on coal usage: China's industrial structure, energy structure, and profit structure are all closely linked to coal usage. For example, electric vehicles and hydrogen technology are advancing so rapidly that fuel vehicles will be soon replaced by them. However, thermal energy is still the main source in electricity supply. Power generation industry's technical progress has been very slow. Switching from petrol-powered cars to electric ones is just replacing petrol with coal. Therefore, it is of great challenge to reduce the coal consumption to 20%-30% in the energy structure. Nevertheless, such requirement has been raised in both the 14th Five-Year Plan and the Conference of the Central Finance and Economics Committee.

Therefore, it is tremendously challenging for China to adjust its energy structure. On the bright side, China's renewable energy development has been rapid, and relevant policies have evolved since two, three years ago. There used to have a uniform pricing system for new power generation projects based on regional or provincial average costs, and now it is replaced by bidding. The marginal cost of renewable energy generation has dropped significantly.

With effective policies, China's renewable energy industry has obtained great progress. It is still relatively promising to substantially increase the proportion of renewable energy, with one or two institutional obstacles to overcome. I have two suggestions in this regard:

The first is to build a unified national market. In the past, experts generally believed that the problem with China's energy system was the monopoly of the State Grid, which needed to be subdivided into smaller grids. But nowadays it doesn't seem to be the case anymore. According to our investigation, the real obstacle to the development of renewable energy is local blockade, not the dominance of the State Grid. China's renewable energy is unevenly distributed, especially in underdeveloped areas where renewable energy is abundant. Electricity is generated but not exposed to remote orders. It is necessary to remove the local blockade. The National Development and Reform Commission has issued policies to address this problem in the past few years, which seem to have had little effect.

The second is to establish a distributed energy network. In the Northern China, the state should endorse more on its energy reform, and speed up the development of rooftop photovoltaics. Rural households have roof property rights, and there is no property right barrier to promote photovoltaic power gen-

eration. If more support is given by the state, it can remedy the loss of energy in the conversion of coal to gas and electricity, and it may be beneficial to China's energy structure reform. In the reform of energy structure, technology and cost are no longer the bottleneck. The next focus is to surpass institutional obstacles.

2.The Effects of Carbon Neutrality in the Ecosystem Have Reached Unprecedented Heights

China had committed to plantation of forestry in the past, but that was supplementary, and was not included in China's emission reduction results.

China's forest resources have grown continuously, which is unseen in other developing countries. China's forests absorb a large amount of carbon dioxide. Now, China has taken comprehensive considerations of ecological progress, ecological restoration and industrial emission reduction altogether to better equip us with climate actions, which will greatly reduce the cost of carbon reduction for the whole society.

China is relatively advantaged in this respect. We should value the potential of the ecosystem. However, to achieve its full potential, there are also some institutional problems that need to be further resolved. I have three suggestions in this regard:

The first is to prevent forest degradation. Currently, 60%-70% of China's forests are natural, half of which are state-owned areas where forest degradation and deforestation are severe. From the perspective of carbon sink, reducing tree-cutting is not sufficient. Healthy forest ecosystems may be carbon sinks, but unhealthy forests may become carbon sources. Many natural forests in our country are degraded forests, which are likely to have become carbon sources already. We need active human intervention to improve forest productivity in order to contribute to the carbon neutrality goal.

The second is to complete the ongoing re-

50 percent

of China's natural forests are state-owned, and face degradation and deforestation

form of the state-owned forestry system. Since 2016, the state has implemented a total ban on logging of natural forests, hoping to reduce the degradation of natural forests in state-owned forest areas and increase forest resources. From the perspective of national climate action and the ecological environment, a total ban on logging of natural forests does not serve the purpose. It is crucial to accelerate forest productivity to contribute to the country's carbon neutrality goals, which is very difficult to achieve under the original system. The reform of the forest resource management system in state-owned forest areas must be resumed.

The third is to expand the market scope of forest products. For example, the southern fir can stay unrotten for two to three hundred years without any treatments. Many old buildings in Fujian from two to three hundred years ago still stand intact. Using wood in construction can achieve multiple years of carbon sequestration. If we build wood-structured houses and plant trees at the same time, the new afforestation will add up the carbon sinks. At the same time, as a building material, wood can replace reinforced concrete which has a high carbon footprint, and can also contribute to the country's green and low-carbon transition.

3.Changes in the Policy System

In the past, environmental protection mainly relied on administrative measures. In the 1990s, the "Zero-Point Action", "Shutdown of the 15 Types of Heavily Polluting Small Businesses", and "11th Five-Year" energy conservation and emission reduction, and the environmental police in the past few years were implemented to address the water pollution. They rely on administrative measures such as "shutdown and transfer". These administrative measures are effective in the short term, but their social cost is extremely high and they are especially easy to rebound.

The environmental protection policies in the future may have to undergo a major transformation. During the 14th Five-Year Plan period, China's economic development is still under great pressure. At the same time, environmental protection regulations have been superimposed, especially the commitments of peaking carbon dioxide emissions. The conflict between development and emission reduction will become unprecedentedly prominent.

To mitigate this conflict, the primary method is through proper economic policies, since they have the lowest social cost, are more sustainable, and have relatively little rebound. It is necessary to intensify efforts in the implementation of economic policies, especially without major technological breakthroughs that would adjust the energy structure.

From an environmental perspective, China has mainly achieved the transformation of the growth model from the miraculous growth of the past few decades to conventional growth. China has achieved market-oriented allocation in the product field, but still has a high level of control in the factor market. The so-called miraculous growth is ultra-high-speed growth at the cost of lowering the factor markets, which is unsustainable. In fact, en-

vironmental factors should also be included in the depressed or distorted factor market. The prime reason for the ultra-high growth, including the phase after China joined the WTO is that China's environmental factors are cheaper.

It is necessary to raise the carbon emission's price to correct the distortion of the factor market, and there must be a proper fiscal and taxation policy. The former Minister of Finance Lou Jiwei proposed that environmental taxes are part of China's comprehensive fiscal and taxation system reforms. China has made some explorations on carbon pricing, such as carbon trading, and the implementation of a national carbon market.

In my opinion, carbon taxation is superior to carbon trading. The most important issue of environmental law enforcement in China lies in the initiative of local governments, because environmental supervision and environmental law enforcement mainly rely on them as well. If the initiative of local governments cannot be activated, as in the past 30 to 40 years, environmental protection will be difficult to implement. The best approach to promote the initiative of local governments is to combine their actions with revenue through environmental and carbon taxations. By pricing carbon, companies will be aware of the cost of carbon emissions. If the emission becomes too expensive, they will be more proactive in reducing carbon emissions.

Therefore, it is pivotal for China to value the use of economic policies during the 14th Five-Year Plan period. We already have abundant existing policies, but the environmental protection department and the energy department need to shift their mindsets and treat economic policies as the primary tool for carbon neutrality and carbon emission reduction, instead of relying on administrative measures and campaign-style emission reductions.

Purposeful and transformative innovation for carbon neutral and inclusive urban futures

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Abstract

City authorities around the world have demonstrated their willingness to make bold commitments to climate action and to experiment with alternative systems, often in stark contrast to higher levels of government. Implementation of city climate strategies will likely require institutional innovation through experimentation – not only to enable the deployment of existing technologies, through which significant emissions reductions are possible, but to establish mechanisms for collective problem-solving and alternative measures of the value of innovation. In setting priorities and objectives for implementation, local government must reflect on how transitions to carbon neutral cities will maintain essential infrastructures and services and support inclusion, wellbeing, and justice. These questions are relevant to critical concerns around new ways of financing the decarbonisation of urban built environments. Transformative innovation policy requires moving beyond technological invention and economic growth towards institutional innovations that promote democratic process, fair distribution of costs and benefits, and the strengthening of public goods and services.

1.Introduction

There is no doubt that business as usual is not an option if the worst climate change impacts are to be avoided within the next decade. The Intergovernmental Panel on Climate Change (IPCC) (2021) latest report re-affirms the imperative of reaching net zero emissions by 2050 to avoid the catastrophic human and ecological impacts of current global warming trajectories. Moreover, existing global climate commitments by nation states under the Paris Agreement are dangerously lacking in ambition and near-term implementation plans (UNFCCC, 2021; UNEP, 2020). Nevertheless, commercially viable technologies offer significant emissions reduction potential. Research by the Coalition for Urban Transitions (2019) suggests that almost 90 per cent of Green House Gas emissions from buildings, materials, transport, and waste in cities can be reduced by 2050 using existing and commercially available technologies. The International Energy Agency's (2021) net zero emissions roadmap to 2050 similarly highlights that "all the technologies needed to achieve the necessary deep cuts in global emissions by 2030 already exist" (p. 14) and, in the case of renewable energy, are cost competitive. The persistent discrepancy between the availabil-

Research by the Coalition for Urban Transitions (2019) suggests that almost 90 per cent of Green House Gas emissions from buildings, materials, transport, and waste in cities can be reduced by 2050 using existing and commercially available technologies. The International Energy Agency's (2021) net zero emissions roadmap to 2050 similarly highlights that the technologies needed to achieve the necessary deep cuts in global emissions by 2030 already exist

ity of low carbon technologies and their wider implementation by cities raises critical questions regarding effective policy and institutional change.

Innovation drives systems change through the application and mainstreaming of new ideas, knowledge, products, processes, and policies. While technology start-ups might garner more attention (Clark, 2021), institutional innovations are a critical part of the transition to carbon neutral cities. The Global Covenant of Mayors for Climate and Energy (GCoM), launched in 2018, represents over 10,000 cities with the aim of promoting and accelerating an ambitious "agenda for change." GCoM's Innovate4Cities initiative establishes research and innovation priorities for supporting city climate action and include governance processes alongside technological interventions. Building on the Global Research and Action Agenda (GRAA) (World Climate Research Programme, 2019), the Innovate4Cities program spans how cities can prioritise action (including co-benefits for vulnerable populations) and establish effective governance frameworks and new financing approaches, as well as solutions across urban planning and design, buildings, energy, water, waste, transportation, and food (GCoM, 2018). Recent analysis of city climate strategies as part of this initiative demonstrates that city authorities are explicitly supporting research and innovation (R+I) activities in their action plans. R+I type actions identified include knowledge generation through research into climate problems and potential solutions; learning through monitoring, evaluation, and feasibility assessments; and testing through pilot projects (Hadfield et al., 2021).

In contrast to narrow conceptions of innovation oriented towards technological development and economic growth, innovation policy discourse is increasingly turning to the direction of innovation processes – in other words, the intended social and environmental outcomes of innovation (Schot and Steinmueller, 2018). How might local governments approach broader conceptions of the purpose and value of innovation for inclusive, carbon neutral cities? Drawing on existing theory and research, the next section discusses how institutional innovation facilitates new stakeholder collaborations and collective problem-solving as necessary for wider systems change. I then discuss how the concept of "transformative innovation" allows for greater attention to social justice outcomes with examples of novel city climate finance mechanisms. Local government can play a role in driving urban sustainability transitions that deliver public goods and wellbeing outcomes, not just growing profits for private corporations.

2.Institutional innovation and collective problem-solving in cities

To achieve the emissions reduction potential of urban areas, city authorities still face a range of challenges and path dependencies, including constrained authority, siloed governance and limited policy alignment across different levels of government, and a lack of resources (UN-Habitat, 2020). Driving decarbonisation of key emissions sectors beyond local government's own assets and operations (Palermo et al., 2020) requires rethinking incumbent systems of provision and governance. Indeed, experimentation is now a recognised feature of urban climate responses as a mode of testing alternative systems, evidence-building and learning, and deliberation among diverse stakeholders to define problems and potential solutions (Bulkeley, 2021). The "urban living lab" approach established in Europe is one example of an intentional, geographically embedded, cross-sectoral, and participatory method of trialling new social and technical systems (Voytenko et al., 2016). Effective experimentation requires reflexivity and organisational learning – including tolerance for failure – to evaluate outcomes, apply lessons, and scale up demonstrated solutions internally and in different contexts (Coenen and Morgan, 2020; Hughes et al., 2020; Peng et al., 2019). A global survey by Organisation for Economic Cooperation and Development (OECD) and Bloomberg (2019) identifies these dimensions as constitutive of the innovation capacity of city governments: risk taking, data management, citizen engagement, use of digital technologies, organisational change, human-centred design, and new financing partnerships.

The COVID-19 pandemic has demonstrated city authorities' capacity to innovate through municipal governance. The public health emergency has "loosened institutional constraints and policy imaginations and provided a mandate for change and deepening governance experimentation" –while also highlighting the "fundamental importance of state capacity and public resources in underpinning urban functioning" (McGuirk et al., 2021, p. 1, 2). In early responses to the pandemic, a United Cities and Local Governments

(UCLG) survey of cities identified innovation in "leadership and authority, cooperation and collaboration across key stakeholders, and information technology and data management" (Davis and Willis, 2020, p. 2). City authorities engaged stakeholders through consensus-based decision-making (Barcelona, Spain) and transparent communication and social research (Bogotá, Colombia). City authorities adapted surveillance capacity and big data for virus contact tracing (Seoul, South Korea), and benefited from coordinated multilevel governance through flexible emergency budgeting for rapid response to localised vulnerabilities (Gauteng, South Africa).

In line with these recent forms of urban governance innovation as problem-solving, innovation policy discourse is turning more explicitly to the direction of innovation processes – in other words, the intended social and environmental outcomes of innovation in response to global grand challenges (Schot and Steinmueller, 2018). Contemporary understandings of innovation highlight the role of a range of stakeholders and different forms of knowledge and learning processes from a systems perspective (Edler and Fagerberg, 2017). In contrast to earlier linear models of development based on the commercialisation of science and knowledge through Research & Development investment, innovation is understood as being generated through complex interactions between technologies, institutions, business strategies, and user practices, where formal and informal institutions can enable and constrain innovation. Nevertheless, the broader systems approach to innovation policy still risks a limited focus on creating enabling conditions for innovation while leaving the direction and outcomes of innovation to markets (Diercks et al., 2019). Market-oriented interventions treat climate change and poverty as externalities and thus secondary to measures of economic growth, productivity, and competition which continue to drive uneven development and urban inequality (Schot and Steinmueller, 2018).

Challenge-oriented innovation entails collec-

10,000 cities

represented in The Global Covenant of Mayors for Climate and Energy (GCoM)

tive priority setting across sectors and levels of government which may challenge dominant perspectives and involve competing interests (Schot and Steinmueller, 2018). In contrast to technological "revolutions" led by elite academic and technology experts, enabled by public funding and the creation of new markets, this policy approach emphasises broad participation of citizens in agenda setting and implementation (Diercks et al., 2019). As mentioned above, an openness to experimentation and reflexivity is fundamental, acknowledging uncertainty, anticipating unintended consequences, and practicing ongoing monitoring, evaluation, and learning. In doing so, stakeholders must question their assumptions and preferences to avoid a narrow focus on optimising incumbent systems (e.g. car-centric urban development and mobility systems) (Schot and Steinmueller, 2018). This is an inherently political process as environmentally and socially regressive systems, such as continued subsidies for fossil fuel industries, require active destabilisation.

Challenge-oriented innovation has been operationalised in the form of "mission-oriented" innovation policy. Economist Mariana Mazzucato (2021, p. xxiv) has popularly argued for a solutions-based, "mission economy" focused on goals that "really matter to people and to the planet." Inspired by the US moon landing, mission policies align ambitious but clear, measurable, and time bound targets to societal problems, to then catalyse cross-sectoral experimentation and innovation across relevant domains and a broad project portfolio. For example, the European Commission's proposed mission to achieve 100 climate neutral cities by 2030 formalises multilevel governance coordination, bottom-up citizen engagement and participation, and access to finance (Gronkiewicz-Waltz et al., 2020). A narrower, techno-scientific approach to innovation within a missions framing can be seen in the Mission Innovation (MI) program which emerged from COP21 in Paris in 2015. MI focuses on accelerating development of new clean energy technologies (with improved performance and reduced cost), to complement support for deploying existing technologies and processes through the Clean Energy Ministerial (CEM) mechanism (Diercks et al., 2019). In contrast, Global Covenant of Mayors for Climate (GCoM) (mentioned above) mobilises a broad approach to innovation with social and environmental purpose to accelerate action on climate change by and for cities. GCoM's agenda addresses the "demand side" of innovation, including housing, mobility, and waste, and supports practice-oriented learning (between cities) (Diercks et al., 2019).

3.Transformative innovation and social purpose

How can the carbon neutral cities agenda seed innovations that centre the wellbeing of all citizens? As highlighted above, experimenting with new governance approaches to address urgent societal and climate challenges provides space for learning with the potential to drive wider institutional change. At the same time, the rapid implementation of institutional innovations in the context of COVID-19 has raised questions around how to ensure innovation processes remain inclusive while avoiding the reproduction of existing socio-spatial inequalities in the city (McGuirk et

al., 2021). Others have considered the potential for place-based collaborations between local government, universities, and businesses such as the Melbourne Innovation District – focused on stimulating creativity and new applications of science and technology – to pursue renewed objectives of "care, solidarity and collective action" in response to ongoing social disruption (Håkansson and Davidson, 2020). Local governments and city networks have articulated how amplified inequalities laid bare through the pandemic reinforce the need for city climate responses to work to overcome resource extractive and exclusionary economic systems (C40 Cities, 2020).

While municipal entrepreneurialism is typically associated with outsourcing, tourism, and attracting private investment, with ambiguous social welfare implications, innovation within local government through the identification of new services can cultivate a more progressive local redistribution of resources (Phelps and Miao, 2020). A foundational economy model of innovation and urban development (Engelen et al., 2017; Marques et al., 2018) highlights the role of "mundane innovation" generated through the deployment of existing technologies (e.g. Butcher et al., 2020, p. 17), interventions in everyday practice, and public services provision as key to transformative change. A foundational economy model represents a radical shift in how the outcomes of innovation are conceived. The ideal role of public policy is to secure the supply of basic goods and services for all citizens – without consumption of fossil fuels and ensuring ecosystem health – rather than the 'zero sum' game of securing competitive economic advantage relative to other cities and regions (Coenen and Morgan, 2020). This approach can be seen in the United Kingdom energy sector where local governments (post-energy market liberalisation/privatisation) have established municipal-owned energy service companies Energy Service Companies (ESCos) that provide commercial energy supply while seeking to alleviate fuel poverty, decarbonise energy supply, and reinvest in the local community (e.g. Bristol Energy).

To more explicitly centre social justice, the concept of transformative innovation has been defined as social innovation that "challenges, alters and/or replaces dominant institutions" (Avelino et al., 2019, p. 196). Efforts to mitigate and adapt to climate change in cities risk entrenching urban inequalities – and indeed, failing to address root causes of climate change and environmental degradation – without intentionally addressing existing structures that limit accessibility and democratic governance of essential infrastructures, other public services, and local environments, and the rights of Indigenous peoples (Bulkeley et al., 2014; Westman and Castán Broto, 2021). One way to think about these relations in practice is to consider how urban climate change interventions are financed.

As the quantity of urban climate finance needed to decarbonise and adapt urban built environments looms large (CCFLA, 2021), prospects for "unlocking" investment pipelines for city climate strategy implementation are high on the agenda of decision makers and practitioners. In a 2020 survey of city practitioners around the world by the Global Covenant of Mayors for Climate and Energy (GCoM), "innovative strategies for financing climate action" was considered the most beneficial new insight to prog-

A foundational economy model represents a radical shift in how the outcomes of innovation are conceived. The ideal role of public policy is to secure the supply of basic goods and services for all citizens – without consumption of fossil fuels and ensuring ecosystem health – rather than the 'zero sum' game of securing competitive economic advantage relative to other cities and regions

ress city climate action (Hadfield et al., 2021). At the same time, existing research highlights the social and spatial trade-offs associated with private finance and standardised calculations of risk and return, which undermine public goods and democratic accountability. These processes include uneven access to credit, debt servicing obligations, profitability thresholds for investment, opaque infrastructure ownership, redistribution of public funds to private firms (Dowling, 2017; Mazzucato, 2018), and outsized corporate power. Indeed, as Mazzucato (2013, 2017) argues, the public sector has always played an important role in taking risks through early investment in Research & Development, however this role is typically underplayed or ignored in favour of private sector entrepreneurs and venture capitalists. As a result, the public sector rarely reaps the financial rewards of such investment which in turn affects the public sector's capacity to reinvest in the public interest. This concern is significant given the uneven capacity of local governments to generate revenues and provide services as a key barrier to climate action (World Climate Research Programme, 2019).

The qualities of climate finance flows – including who provides funds, how costs and benefits are distributed, and who has a say in these decisions – will determine the extent to which financial innovations maintain business as usual accumulation and exclusion, or seed more inclusive and democratic alternatives (Hadfield, 2021; Hall et al., 2018). Precedents for public finance structured according to social objectives include income-contingent loans for higher education in Australia. Through this mechanism, upfront credit is provided while repayments are deferred until future income thresholds are reached to limit financial burdens and ensure equitable access (Spies-Butcher and Bryant, 2018). In the context of municipal climate governance, place-based financing models demonstrate the potential for inclusive and collaborative investment that builds local wealth (McHugh et al., 2019). A well-known example is the energy co-operative, which involves community co-ownership and -management of local renewable energy facilities through the purchase of individual shares (equity) (Hatzl

et al., 2016; Seyfang and Haxeltine, 2012). These schemes emphasise environmental objectives and prospects for local wealth distribution over commercial profitability. In a different way, an experimental local government scheme in Melbourne established interest-free loans for low-income homeowners to install rooftop solar and save money on electricity bills (Hadfield and Cook, 2019). These mechanisms highlight the important roles that local authorities and community groups can play in establishing social and environmental conditions around capital investment in cities.

4.Lessons

Existing research discussed above points to key considerations for urban authorities to conceptualise and apply innovation in policy and practice:

- Institutional changes can be seeded through experimentation with alternative social and technological systems that provide space for learning-by-doing and learning through failure, supported by deliberation of diverse stakeholders. Meaningful change requires reflexivity and effective organisational processes for evaluating outcomes and scaling up demonstrated solutions.

- Institutional innovation processes should unsettle assumptions, incumbent interests, and conservative ideologies around the core business of local government and market-led development. Recognition of social and First Nations (in)justice is a critical starting point for urban climate governance innovation to avoid entrenching existing structures of socio-economic exclusion, inequality of access (e.g. to high quality essential infrastructures and services), and concentration of wealth among the few.

- Mission-oriented innovation policy exemplifies a framework for collective problem solving around a specific and ambitious challenge which may be operationalised for local participatory planning on key targets.

- A foundational economy model of innovation

Recognition of social and First Nations (in)justice is a critical starting point for urban climate governance innovation to avoid entrenching existing structures

refocuses innovation policy on more "mundane" innovation in the deployment of existing technologies, changes in everyday practices, and public services provision essential for thriving communities.

- A transformative innovation model calls for adapting and reconfiguring dominant institutions through the above mentioned processes, where local authorities and community groups can, for example, establish social conditions around climate finance to challenge prohibitive financial thresholds of private investors in favour of social and environmental values and needs.

5.Conclusion

Implementation of ambitious city climate targets requires a shift from business as usual urban governance. This paper introduces emerging frameworks that inform experimentation and institutional change, including mission-oriented innovation, foundational economy, and transformative social innovation (summarised in Section 4). Place-based innovation processes driven by social and environmental priorities offer an important counter to narrow conceptions of innovation defined by technological invention and competitive advantage, often led by large for-profit corporations. Local governments may be uniquely positioned to advance new forms of purposeful innovation to address local climate problems through democratic participation and cross-sectoral collaboration, illustrated in part by city responses to COVID-19. Setting priorities and objectives for implementation of city climate plans provides an opportunity for local authorities to innovate through the application of new social value propositions, expansion of high-quality essential infrastructures and public services, and the fair distribution of costs and benefits.

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Achieving carbon neutrality: enabling and scaling up local urban community-led initiatives

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Abstract

Local communities in cities play a key role in tackling climate change and transformation towards carbon neutrality. Community-led initiatives often are concerned with harnessing and supporting communities to identify and define what is important to them, and take lead in identifying and implementing solutions. This article underscores the powerful change that can occur in local communities and which local authorities can support and benefit from. The paper seeks to promote community driven climate action for transformative outcome, and encourage community innovation to drive global ambition for a climate resilient future and re-imagine solutions by sharing, learning and good practices. Potential benefits of community led initiatives include consideration of a wider range of innovations and interventions to tackle climate change, reducing the risk of policy and program implementation failure, increased understanding of the climate change and carbon neutrality, and increased trust between local government and communities. Community led initiatives play an essential role in societal move towards carbon neutrality and sustainable future. Creative responses, shared knowledge and involvement of local communities is required to meet challenges posed by climate change. The community-led actions highlighted in the article are innovative, scalable and replicable to tackle climate change and help achieve carbon neutrality.

Keywords: Carbon neutral, grassroots solutions, innovation, cities and climate, Community led, sustainable

1.Introduction

Local communities through innovation and actions may hold one of the keys to supporting efforts for zero emissions and overcoming some of the climate change challenges. A number of local communities have shown that by using local solutions it is possible to move the society towards carbon neutrality, combat climate change and create opportunities. There is a basis for supporting interventions that emanate from local communities and are geared towards reduction of carbon emissions.

First, local communities can play vital roles as partners in ensuring national and local governments and businesses take their commitments to achieve carbon neutrality seriously. One important step is to ensure governments

and businesses provide and implement plans for action in nationally determined contributions (NDCs) that define targets and actions to reduce emissions.

Second, community-led initiatives provide local knowledge for strengthening required capacity, and a push to focus on the scale at which impacts are felt, and link the actions with outcomes. Community-led solutions embody an approach that addresses environmental, economic, and social issues simultaneously, recognizing the wholeness of people's lives.

Third, harnessing innovation and utilizing skills, knowledge and potential of local communities is critical in the transformation towards carbon neutral cities. Adapting to climate change requires innovation, creativity, experimentation and, above all, partnerships.

Also, local communities ensure that solutions proposed and implemented towards carbon neutrality improve livelihoods. For example by ensuring that transformation towards carbon neutrality creates opportunities for jobs and growth.

The pursuit of carbon neutral cities is not just a matter for national and city policymakers. Local communities play a critical role in this transformation. Local communities have not been left behind, but many are joining or leading efforts to tackle the critical challenges of climate change. Making available experiences of some of the local communities taking positive action is especially important - to inspire more local communities to join these efforts, trigger wide ranging changes in how companies and countries operate, help improve understanding of challenges and opportunities in tackling emissions.

Despite the successes and promises, many community solutions remain unknown. The solutions in this article are some exceptional examples of grassroots level innovations that affect real change towards reduced carbon emissions. The challenge is how to sufficiently replicate and scale up community-led solutions to make significant change.

The cases demonstrate and showcases the benefits of community led solutions towards carbon neutrality, encouraging further support, replication and scaling up. The cases provide new, practical and innovative practices, approaches and tools, and can be replicated and scaled up.

2.Case studies

2.1 Rosario urban agriculture: Reducing greenhouse gas emissions with urban agriculture

Argentina's third largest city has created an urban agriculture program, which has evolved from an approach to put food on the table, to a tool for job creation, and more recently to a strategy for tackling climate change. The residents of Rosario, Argentina's third-largest city, are no strangers to crises.

When the country's economy collapsed in 2001, a quarter of Rosario's workforce was suddenly unemployed; more than half of its population dropped below the poverty line. Faced with skyrocketing food prices and shortages, some residents resorted to looting

supermarkets for food.

While residents struggled with an economy in freefall, another crisis loomed in the background. Climate change was heating up the city and making rainfall more erratic, leading to both flooding in Rosario and fires in the nearby river delta.

The Municipality of Rosario responded with the Urban Agriculture Program, a finalist for the 2020-2021 Prize for Cities, which spotlights innovative approaches to tackling both climate change and urban inequality. The program, which gives low-income residents access to underutilized and abandoned public and private land to cultivate food, was originally intended to alleviate food scarcity and provide economic opportunities. Over the years, the municipality evolved the program into a cornerstone of its inclusive climate action planning.

Prior to the economic crisis of 2001, many farmers in Rosario's state of Santa Fe, an agricultural hub, were cultivating soybeans for export. By the early 2000s, Rosario had started to depend heavily on imported agricultural products cultivated with extensive use of pesticides to meet its own food demand.

The city's Urban Agriculture Program (Programa de Agricultura Urbana, or PAU) began supplying local groups with tools, materials, seeds and training on agroecological production — growing produce without chemicals — in 2002. The program quickly expanded to cover 75 hectares of the city, including seven Parques Huerta, or Vegetable Garden Parks, and various smaller neighborhood plots that were formerly underutilized or abandoned land.

To establish urban farming as a source of livelihood, the municipality also created spaces throughout the city for several permanent and pop-up markets, where urban farmers could sell locally grown produce and homemade goods like pickled vegetables, sauces, syrups, organic cosmetics and preserved fruit and jams.

Today, almost 300 urban farmers have temporary ownership of public and private land. About 65% are women who grow produce and sell it in Rosario's markets. The municipality has also expanded urban agriculture into public spaces, schools, marketplaces and a variety of social programs, especially those for youth and elders, establishing a culture around food production. Vegetable Garden Parks in low-income communities have become critical locations to carry out other social programs, including those for education and youth development. For example, municipality staff trained more than 2,400 families and 40 schools on agroecological production, which have since started their own vegetable gardens.

Besides giving people jobs and new sources of livelihood, there are important climate benefits gained from the Urban Agriculture Program. When monoculture triumphed over diversified food production, the city started sourcing food from more than 400 km away, creating a supply chain that generates considerable greenhouse gas emissions. Today, almost 2,500 tons of fruits and vegetables are agro ecologically produced in Rosario each year. Localizing vegetable production creates 95% fewer GHG emissions than produce imported to Rosario, according to a study by the National University of Rosario and RUAF Ur-

ban Agriculture and Food Systems.

The expansion of urban agriculture assists in reducing greenhouse gas (GHG) emissions not only by producing food but also by reducing the amount of food transported from farming areas and therefore reducing the food mileage.

2.2 Resolve: Trash to Cash recycling solid waste, reduce landfill emissions and create job opportunities

The South Asian Forum for Environment's Resolve: Trash2Cash initiative is an innovative solution to the city of Kolkata's solid waste problem. It is an independent community enterprise led by people who live in slums and are trained and paid to collect and recycle corporate and household waste in urban areas.

Improper waste management can generate more greenhouse gas than required – appropriate waste management needs to be applied to mitigate GHGs emissions. Trash2Cash initiative manages solid wastes in a way that reduces GHG emissions and enables the city of Kolkata to adapt to future changes.

The initiative segregates waste at the source, diverting organic waste from the landfills to produce compost. Paper waste is recycled into marketable handicrafts in a workshop run by women.

Each month, slum residents collect and recycle 1,000 kg of waste paper and compost 2,000 kg of food waste. This is reducing CO_2-equivalent emissions by 520 metric tonnes each year. The enterprise aims to recycle 70-85% of corporate and household waste from urban areas in Kolkata.

More than 5,000 tonnes of solid waste is generated every day in the city of Kolkata, India. Dumping of this waste is polluting the groundwater and emitting large amounts of methane gas, which is 25 times more potent than carbon dioxide at trapping heat in the atmosphere.

More than 50% of the urban poor are engaged in the waste trade as collectors, segregators or suppliers. But they are exposed to various health risks and earn extremely low wages. Recycle: Trash2Cash is led by people who live in slums and are trained and paid to collect and recycle corporate and household waste in urban areas. This waste is segregated at the source and diverted from the landfills, which are slowly encroaching upon the East Kolkata Wetlands, to produce compost. Paper waste is recycled to produce value-added products in women-led workshops and organic waste is turned into compost.

This community-based solid waste management business model addresses two challenges. It offers people living in slums employment opportunities and it reduces the environmental hazards of open waste dumps.

As a contributor to global climate change, waste ranks third behind energy and transportation. Trash2Cash is recycling solid waste and reducing landfill emissions. The reduction of methane emissions as a direct result of diverting organic waste from the landfills and the recycling of paper is helping to mitigate climate change.

Each month, slum residents collect and recycle 1,000 kg of waste paper and compost 2,000 kg

of food waste. This is reducing CO_2-equivalent emissions by 520 metric tonnes each year.

Trash2Cash is not only scalable but also replicable in other urban poor areas around the world. Other urban areas can replicate the enterprise's supply-driven waste management system. Partnerships can be created with corporate offices that do not have a system for recycling in place. The paper can be easily recycled into products such as pen stands, dustbins, photo frames, etc. The waste collected for compost has a large market demand in the urban, agricultural and government sectors.

2.3 Solar sister is reducing carbon emissions and empowering women

Solar sister is an innovative social enterprise with the mission to achieve sustainable, scalable impact at the nexus of women's empowerment, energy poverty and climate change. It empowers women with economic opportunity and clean energy. It combines the breakthrough potential of portable solar technology with a women driven direct sales network to bring light, hope and opportunity to a range of communities without reliable electricity access.

Solar produces less life-cycle GHG emissions than conventional fossil fuel energy sources. While there may be some GHG emissions produced during the manufacturing and recycling of the solar system, the generation of energy results in zero GHG emissions and zero environmental impact.

Through a micro-consignment model, solar sister entrepreneurs get a 'business in a bag', a start-up kit of inventory, training and marketing support to bring clean energy directly to their customer's doorsteps.

Solar-sister started by training ten women entrepreneurs in Uganda in 2009. To date, the activity has created micro-businesses for 171 Solar sister entrepreneurs in Uganda, Rwanda and South Sudan, bringing the benefits of solar power to more than 31,000 Africans. Solar sister's goal is to make women an integral part of the clean energy value chain in Africa. Every dollar invested in a Solar sister entrepreneur generates over USD 48 in economic benefits in the first year alone, through earned income for the entrepreneur and the cash savings of her customers. For example, a solar lantern costing USD 18 brings USD 163 cumulative savings over a five-year period by displacing kerosene usage. Another USD 45 solar lantern plus mobile phone charger brings USD 225 in cumulative savings in displaced kerosene usage and mobile charging fees over the same period. At one-tenth the cost of solar home systems, customers benefit from increased savings, extended working hours, better indoor air quality and extended study time for children.

Solar sister is the only organization in the world formed with the exclusive mission to build an Africa-wide network of women clean energy entrepreneurs. As the primary consumers of household energy, women are critical for successful adaptation of clean energy solutions. Solar sister was founded on the belief that investing in women is a prerequisite for large-scale adoption of clean energy technologies at a grassroots level. It is this gender inclusive system approach, combined with a women led enterprise-based model to bring sustainable livelihood opportunities to address energy poverty, that makes the Solar

Sister model unique.

Each solar lantern in its 10-year lifetime will replace the use of about 600 litres of kerosene, thereby mitigating about 1.5 tonnes of carbon dioxide (CO_2). The sale of solar products by Solar Sister entrepreneurs so far will help mitigate 9,564 tonnes of CO_2 emissions. At the proposed scaling up, Solar Sister entrepreneurs are projected to mitigate more than 10 million tonnes of CO_2 emissions over ten years, while replacing the usage of 660 million liters of kerosene. The solar lanterns also remove the black soot generated by kerosene, which has been shown by scientific evidence to contribute to global climate change. At the same time, solar mobile phone charging solutions replace the use of cheap and non-recyclable batteries. Solar-powered products also result in improved local air quality and have a positive impact of public health.

Clean energy brings economic and public health benefits, while improving the local environment, mitigating climate change and propelling Africa to a green future.

Solar sister entrepreneurs serve as role models to other women. They build successful businesses, are proud of the income they bring to their families and are able to pay their children's school fees. They no longer depend on harmful and expensive kerosene for lighting needs. Not only are these Solar Sister entrepreneurs building sustainable livelihoods for themselves, they are also mentoring other women in the community, expanding the Solar Sister network to benefit more women with business opportunities and more customers with world class clean energy products, building a momentum of change at grassroots level to address energy poverty and climate change.

Solar sister has the bold vision of ushering a women-driven clean energy revolution in Africa through a highly scalable, marketable and sustainable business model. With 590-million off-grid population, Sub-Saharan Africa is one of the world's biggest markets for portable solar power solutions. Potential demand for modern lighting products is greater than 50 million units. Solar solutions for charging mobile phones present a big market opportunity as Africa continues to top the global mobile phone market growth. By 2015, there will be more than 200 million more African mobile phone owners than grid users and a total of 400 million off-grid phone owners across Africa. This translates into a huge clean energy market for Solar Sister products and services.

Solar sister has laid the foundation for scaling our impact through strong public-private linkages with technology, implementation and enterprise development partners. At the grassroots level, Solar sister partners with organizations with proven track record and linkages with local women's groups to benefit from their existing infrastructure and deep roots in the community.

In Tanzania and Kenya, Solar sister has signed a Memorandum of Understanding with the African Wildlife Foundation (AWF) to integrate Solar Sister's green business opportunity with AWF's conservation efforts. In Kenya, Solar Sister have joined hands with the Green Belt Movement (GBM), the organization of the late Dr. Wangari Maathai, the first African woman and first environmentalist to receive the Nobel Peace Prize. Our partnership will comple-

ment GBM's broader efforts to unlock women's potential as "green agents of change". In Nigeria, Solar sister is partnering with SOSAI renewable energy company and with Azsa Microfinance Bank Ltd. Solar Sister leverage investment for maximum impact and believe that the strength and viability of our work lies in capturing, analyzing, and learning from the program's ongoing impact.

3.Lessons Learned

The case studies highlighted here each show the importance of local communities in transformation towards carbon neutrality. At the same time the case studies demonstrate that by using local solutions it is possible to move the society towards carbon neutrality, combat climate change and create opportunities, and that there is a basis for supporting interventions that emanate from local communities and are geared towards reduction of carbon emissions.

- The mitigation of greenhouse gases in the agri-food sector depends on production and consumption patterns. The urban agriculture program in Rosario shows that local communities can mitigate greenhouse gas emissions in urban areas.

- Without an effective role from cities doing what they need to do to tackle climate change it would be impossible for countries to meet their Nationally Determined Contributions, or to meet the Paris Agreement. But for cities to do that, they need to harness community solutions.

- Local community contribution is required to help science and accelerate carbon neutrality - increase carbon sequestration and promote the farming practices of tomorrow, which are positive for the soil, the planet and food.

- Local communities play an important role in developing carbon neutrality solutions and are undertaking successful innovation in this field in different countries. There is a need for more support and opportunities to engage local communities and provide enabling environments to innovate solutions for addressing greenhouse gas emissions.

4.Conclusion

This article has examined the importance of community-led solutions and innovation to greenhouse gas emissions. Community solutions in different forms, especially innovation, are essential in efforts to reduce pollution, become more efficient in the use of carbon emitting fossil fuels, and stop exacerbating the problem. The article points out the need for identifying, strengthening, replicating and scaling up community solutions to accelerate carbon neutrality, set ambitious targets for net-zero emissions by 2050 and inspire more community and sustainable solutions. The case studies discussed in the article are by no means exhaustive, and neither are they revolutionary. The case studies are meant to encourage local governments to enhance the effectiveness and impact of communities by developing a strong local community innovation environment, promoting opportunities and providing incentives for actors to engage and support community innovation, and en-

hancing effectiveness of community innovation models in tackling greenhouse emissions. The study supports the notion that community innovation and solutions should be considered to accelerate efforts towards achievement of carbon neutrality.

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As the trend of urbanization worldwide keeps gaining momentum, the digital infrastructure supported by Artificial Intelligence and big data is also reshaping cities' governing patterns, so is the interactive mode between human beings and the Earth. One question that must be answered in pursuing carbon neutrality is: What are the tools and technological consensus quantifying our city? And how can we better achieve the integration of systems? The Nobel Prize in Physics 2021 was awarded one-half joint to Japanese-educated American meteorologist and climatologist Syukuro Manabe and German oceanographer and climate modeler Klaus Hasselmann, for "the physical modeling of Earth's climate, quantifying variability, and reliably predicting global warming". Climate issues on earth is a very complex system and the two Laureates exactly contributed to its quantification. Studies by the United Nations Office for Outer Space Affairs and the European Union show that nearly 40 percent of the 17 United Nations sustainable development goals (SDGs) depend on Earth observation and global navigation satellite systems. During the pandemic, governments are utilizing geospatial information, digital programs, and AI-driven risk analysis to empower communities to adapt. The selected articles in this chapter apply Google indexes, satellite remote sensing images, machine learning and other innovative tools to help us better understand urban climate and environment.

CHAPTER TWO:

SMART CITIES AND DIGITAL INFRASTRUCTURE

Can retail investors help to decarbonise cities?

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Abstract

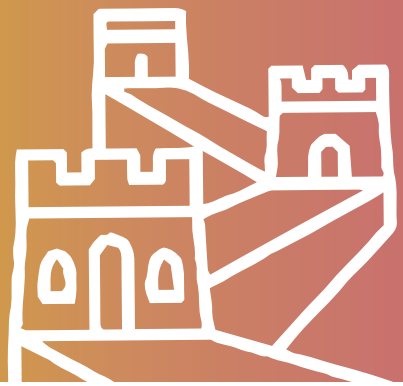
Meeting 'Net Zero' targets implies we are able to deploy decarbonisation strategies quickly and efficiently across all sectors of economic activities. On the global scale cities collectively represent a substantial source of carbon emissions, and in this respect are comparable to any other type of production asset, albeit much more complex in terms of structure and governance. Greening cities and metropolitan areas will require substantial funding injections not only from the fiscal bodies but also from the private finance actors. However, involvement of traditional private sector finance into co-design of carbon-neutral cities often comes with pre-defined agendas. Such partnerships should be therefore crafted carefully in order to ensure not only reasonable investment returns, but also mitigation of adverse long-term consequences, such as fragmented social cohesion fabrics, unsustainable resource allocations and dysfunctional asymmetries between private and public spaces. Given the increasing growth of interest in infrastructure from another type of private finance actor - retail investors - we employ here Google Trends data signals in order to demonstrate how these emerging investment preferences can help to shape urban decarbonization strategies and account for the social agendas on the global scale.

1.Introduction

Modern cities are still closely associated with marked social inequalities, economic and health deprivation levels and environmental degradation, all of which contribute to the perception that urban habitats are far from ideal places for our long-term ambitions for flourishment and prosperity. In the context of growing climate threats and the need to take rapid decarbonisation actions the time has arrived to start considering how we can design and manage urban environments so that they become a font of innovation with respect to water, energy, lighting and social prosperity. It has been already acknowledged that when properly planned, cities can indeed be more productive in terms of clean air and water provision, biodiversity protection and carbon sequestration. And in order to achieve those ambitions substantial amounts of funding streams need to be directed towards sustainable objectives.

With these concepts in mind, back in October 2016 during the third UN-Habitat Conference

Traditional actions for mobilising resources is usually associated with the national and municipal governments, through the expansion of their potential revenue base, including taxation and other fiscal activities. However, the real situation is much more complex than that as in many parts of the world urban infrastructures are involved into the complex mix of ownerships, which can define their financing sources and how they can be balanced and distributed.



on Housing and Sustainable Urban DevelopmentUN member states adopted the New Urban Agenda, a comprehensive and ambitious programme designed to tackle various urban security issues stemming from the exponential growth of the urban population due to mass migration, conflict, and pronounced social inequalities, which are intensifying as a result of the changing climate. Creation of safe and inclusive spaces has long been on top of various sustainable urban agendas and has now become a critical objective to reach truly liveable urban environments which not only provide citizens with spaces to share experiences and create economic opportunities, but also serve as shelters against intensifying natural hazards and sources of continuous provision of the vital resources, such as clean water, food and air. Since creation and maintenance of these functions are expensive, the understanding of how to design and attract sustainable sources of funding, which can expand beyond their traditional metropolitan pools, has become a matter of vital and urgent importance.

Although the New Urban Agenda recognizes the necessity to mobilise resources for its implementation, it does not contain any provisions outlining concrete financing mechanisms. Traditional actions for mobilising resources is usually associated with the national and municipal governments, through the expansion of their potential revenue base, including taxation and other fiscal activities. However, the real situation is much more complex than that as in many parts of the world urban infrastructures are involved into the complex mix of ownerships, which can define their financing sources and how they can be

balanced and distributed. As per today, governments around the world invest a total of about $2.5 trillion a year in transportation, power, water, and telecommunications systems, but this figure w CBB b by vvv v her Fa a as estimated as insufficientfor satisfying demands of prospective growth, especially in the developing world. And whilst the need for investment will continue to grow, the world will need to spend about 3.8 percent of GDP on infrastructure through 2030, an average of $3.3 trillion a year (McKinsey, 2018).

In these contexts Public-Private Partnerships (3Ps) for urban spacesstarted emerging as potential means of improving the quality of urban public finance interventions. Indeed, many countries are already turning to 3Ps and private investors to finance various development projects, such as ecological restorations of natural habitats, which are capable of self-regulating and attenuating toxic pollutants, geomorphological engineering of hazard-prone infrastructure locations, and 'daylighting' or re-purposing of brownfield districts into more inclusive and economically productive areas. While it is a potentially innovative way of funding sustainability-related projects, *privatisation threats* typically carry the risks of negative public perceptions as they quickly imply connotations of social exclusion and unequal access to the newly emerging goods and services.

Emerging models of joint ventures (JVs) between multiple businesses and public sector actors are able to demonstrate pathways to *risk diversification*, where required funds are mobilised for the primary redevelopment projects, which then subsequently attract additional sources of revenues by opening up to various retail investors and thus stimulating economic activity based on cascading principles. As an essential prerequisite for success, these projects specifically point out the advance strategies to achieve 'publicly approved, safe spaces', on top of which other services can be built and established; And these examples also show that there can be strong upfront *intuitive* incentives for private sector actors to enter public space projects - even when there is no obvious indicators for return on investment at the beginning. Moreover, evidence suggests that such multi-stakeholder partnerships between the private sector and local stakeholders can generate trust and lead to a better understanding of local market and consumer preferences, whilst simultaneously reducing the strain on the local fiscal resources.

However, not all examples of 3Ps are exclusively positive, and the evidence suggests that success rates are contingent on several factors. For instance, consideration of the local preferences is absolutely crucial, particularly in cities, where social fabric is already eroded by ethnic, cultural or political conflicts and c sa inconsiderate politics of space organisation can lead to more aggravated divisions. Secondly, privatisation practices can lead to exclusive securitisation, benefitting only certain socio-economic classes, it is therefore necessary to keep in mind the balance, which can be achieved with use of advanced planning methods. Finally, the private investment sector is also undergoing some deep structural changes, where various fast-paced technologies help to make all kinds of asset markets more liquid, i.e., where many available buyers and sellers are numerous, trade

quickly and at a desirable wwww a square a CD and comparatively low transaction costs because the product is standardized and in high demand. Since the drastic decreases in trading costs, institutional investors quickly found themselves competing with index funds that are able to track the markets more efficiently, exchange-traded funds (ETFs), which offer access to the 'baskets of assets' and robo-advisers, which allocate cash to cheap funds according to portfolio-management theories.

These and some other profound structural changes in the investment landscape are also empowered by the data sources, which grow both big and dense in volume. Along with the more traditional data sources, such as assets, liabilities and costs/earnings (i.e., 'fundamental data'), quotes, prices and dividends (i.e., 'market data'), credit ratings and earnings expectation analytics, alternative for traditional finance datasets, such as satellite images, Google searches, news sentiments and Twitter chats also enter this space as far less regularized, highly frequent and more readily available sources of information for individual investors. These trends also opened opportunities for investments, which have been traditionally outside the scope of the sole traders, and those ones also include urban infrastructure.

The case of urban infrastructure as an investment asset is particularly interesting as its development strategies will be able to define the success of both decarbonisation and population growth problems. Urban populations are getting increasingly aware of the fact that infrastructure and built environment adaptations are critical, not only for achieving sustainable development political agendas, but also for their own climate and environmental security. In practice, however, implementation of the myriad of necessary changes can be extremely challenging as transformation can involve not only a wide range of decision makers, but also options, which should correspond to local needs and preferences in the most optimal ways. It has already been identified that in order to meet 'net zero' targets across multiple sectors (including urban agglomerations) we need to work on developing novel long-term planning approaches for changing the built environment and infrastructure that can meet growing social, economic and environmental challenges.

Some literature reviews already mentioned that public preferences for decarbonisation strategies can vary significantly. However, no method currently exists to demonstrate how private finance (and specifically its fast-growing fraction of actors, the retail investors) can use public sentiment information on climate-friendly options available for urban infrastructure markets in order to support transition to the carbon-neutral cities.

2.Google Trends

2.1 Public sentiment data

Public sentiment is a digital indicator, which can be extracted using several established Natural Language Processing (NLP) methods, applied to unstructured text data from various social media platforms, websites, public deliberation forums and other sources of semantic information. In relation to financial applications, the Google Trends platform has been extensively used by researchers, dig-

ital media and finance analysts in order to understand the relevance of public search query data to 'market moves' (i.e., information that would cause any reasonable investor to make a buy or sell decision). Ever since Google Trends became open for public analysis, extracted information has demonstrated that data can be successfully used to improve existing concepts in technical analysis, such as sales volumes, and even for prediction of the market moves (Dimpfl & Jank, 2011).

As a service, Google Trends platform offers its users indicators of the relative popularity of keywords/word combinations over time, across the countries and across time intervals with the earliest signals dating back to 2004. The data is not presented in its raw format, and is scaled from 0 to 100 in order to make the searches comparable to each other. It also offers functions of comparison of the key searches of interest (up to 5 at a time), as well as allows to rank them in various categories and in various geographical regions. Thus, Lim & Stridsberg (2015) mention the most interesting aspect of the data – its capacity to reveal the users' *intentions* and introduced the term 'search volume index' (SVI) for the data provided by Google Trends on the relative popularity of a search term.

In finance, Google Trends has been of particular interest to retail investors, tracking relationships between public search queries ('public attention turned intention factors') and stock markets volatility. The existing academic research therefore agrees that there is some information contained in search volume data that can help improve various financial forecasts.

In the scope of this study we decided to repurpose Google Trends data in order to demonstrate how volumes of public searches for information on the web regarding upgrades of urban infrastructure and the built environment with carbon-neutral options can be re-used to inform private retail investors about more technologically – and socially – sustainable investment opportunities. This ambition was motivated by our prior unpublished works into how people tend to associate urban infrastructure and the built environment failures with more frequent natural hazards, and how those trends correlate with infrastructure dissatisfaction scores (Fig 1a and 1b).

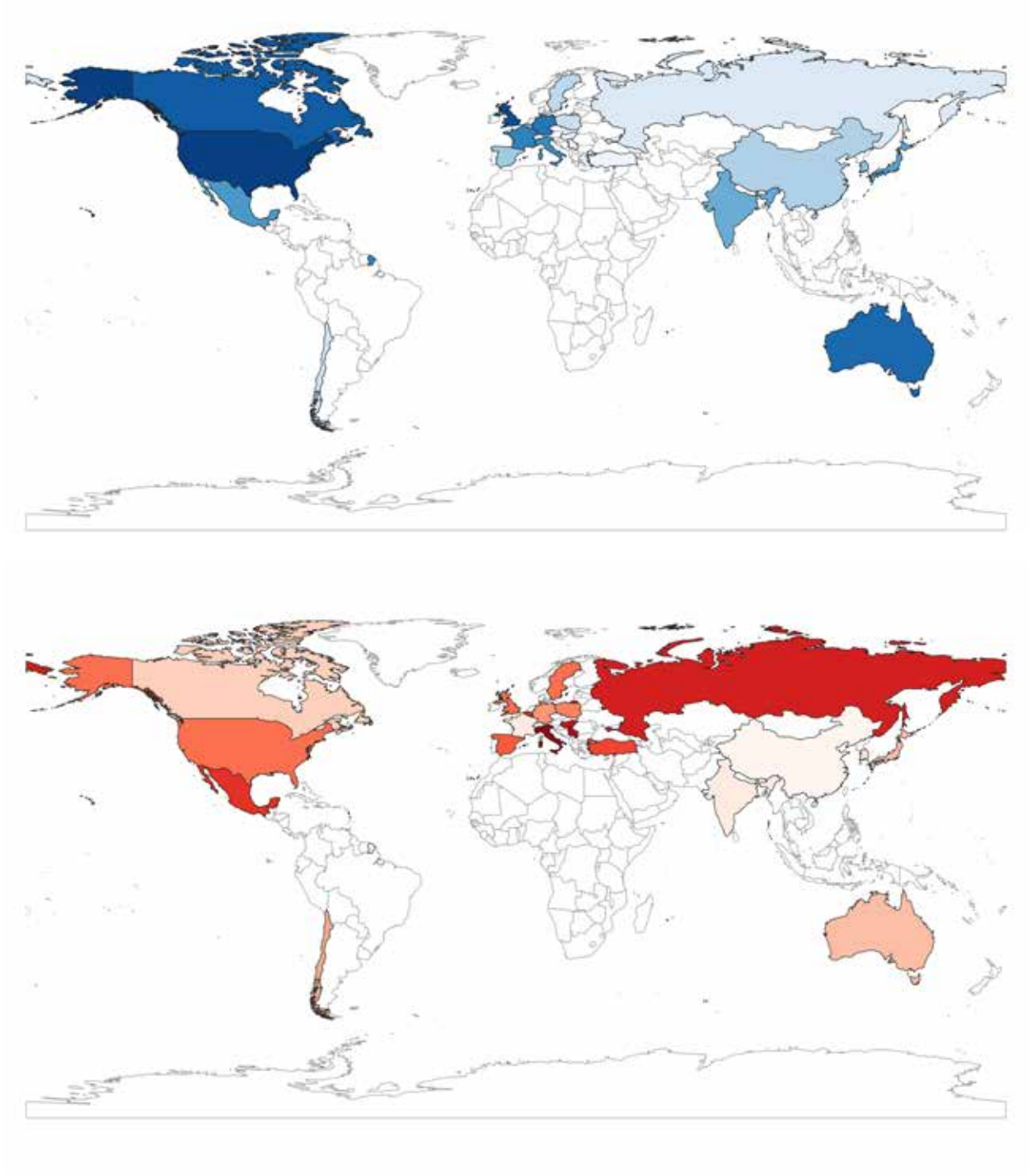


Fig 1a Urban infrastructure failures reported on social media and citizen-participation platforms *(LEFT)* and calculated infrastructure dissatisfaction scores in the corresponding countries *(RIGHT)*

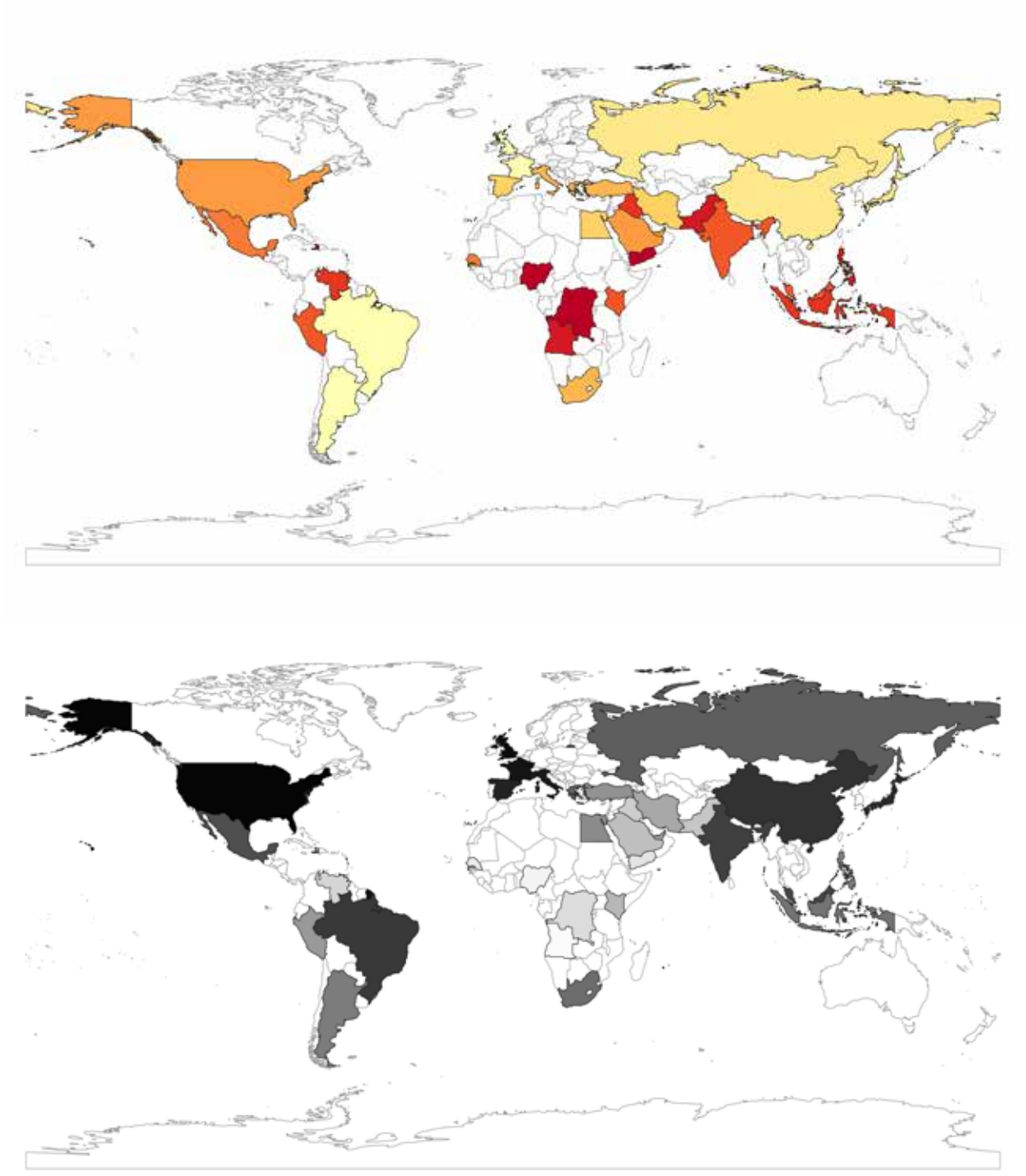


Fig 1b Climate vulnerability of built environments *(LEFT)* and citizen-reported concentrations of 'net-zero' buildings in urban areas *(RIGHT)*. All the choropleth representations are relative within each individual map, where darker shades represent higher and the lighter shades correspond to the lower values, respectively

2.2 The Project Drawdown, and how to include decarbonisation preferences into retail investment strategies

As an inventory of potential decarbonisation options for urban infrastructure we used the options listed in The Project Drawdown. This initiative was conceived as a comprehensive academic undertaking, looking to create the most advanced possible list of temperature drawdown options. The investment indicator indices are constructed by analysing how often certain terms are searched, and in this analysis we used the keywords, which corresponded as closely as possible to the decarbonisation options, listed in The Project Drawdown(Fig 2) However, unlike more established methods based on Google Trends data, which utilise the principle of subtraction of 'bearish' terms from the 'bullish' volumes (a.k.a investor's subjective belief that the market will go down or will start climbing, respectively), we used spatially differentiated subsets of the Google Trend timelines, which capture regional effects of the local decarbonisation incentives on the market moves. And similarly to the company-based approaches, by repurposing 'bearish'/'bullish' term search differences for geographical regions, countries and cities, we are able to capture a lot more differentiated information on the public interest towards individual decarbonisation options.

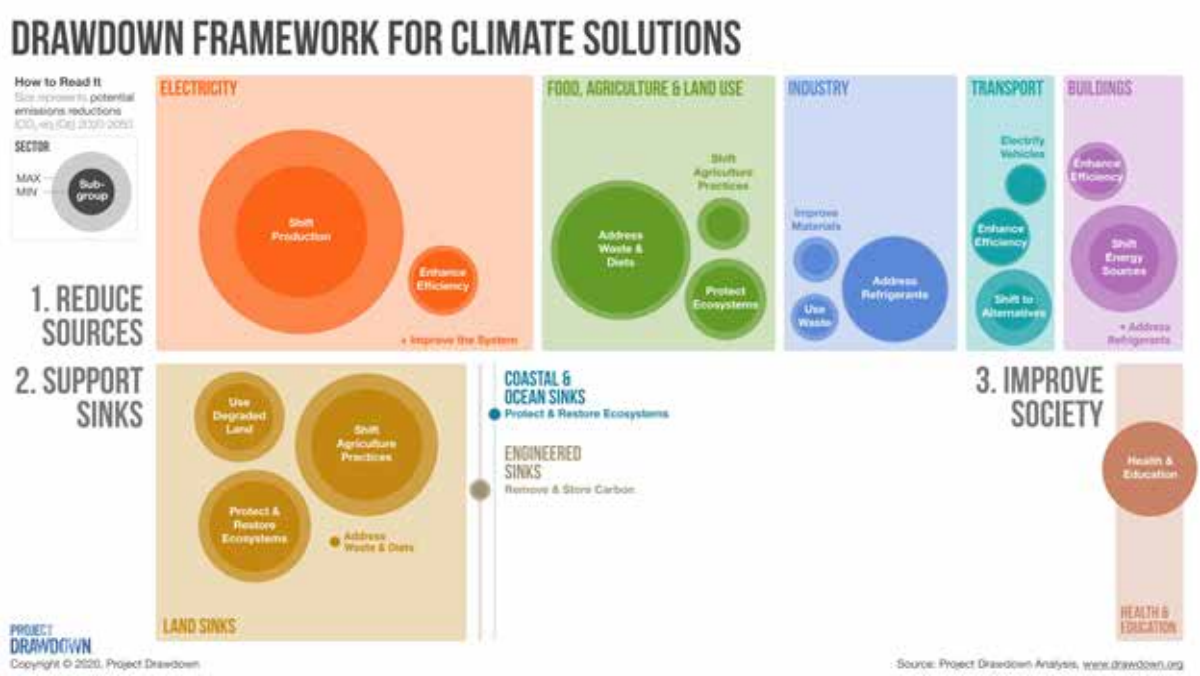
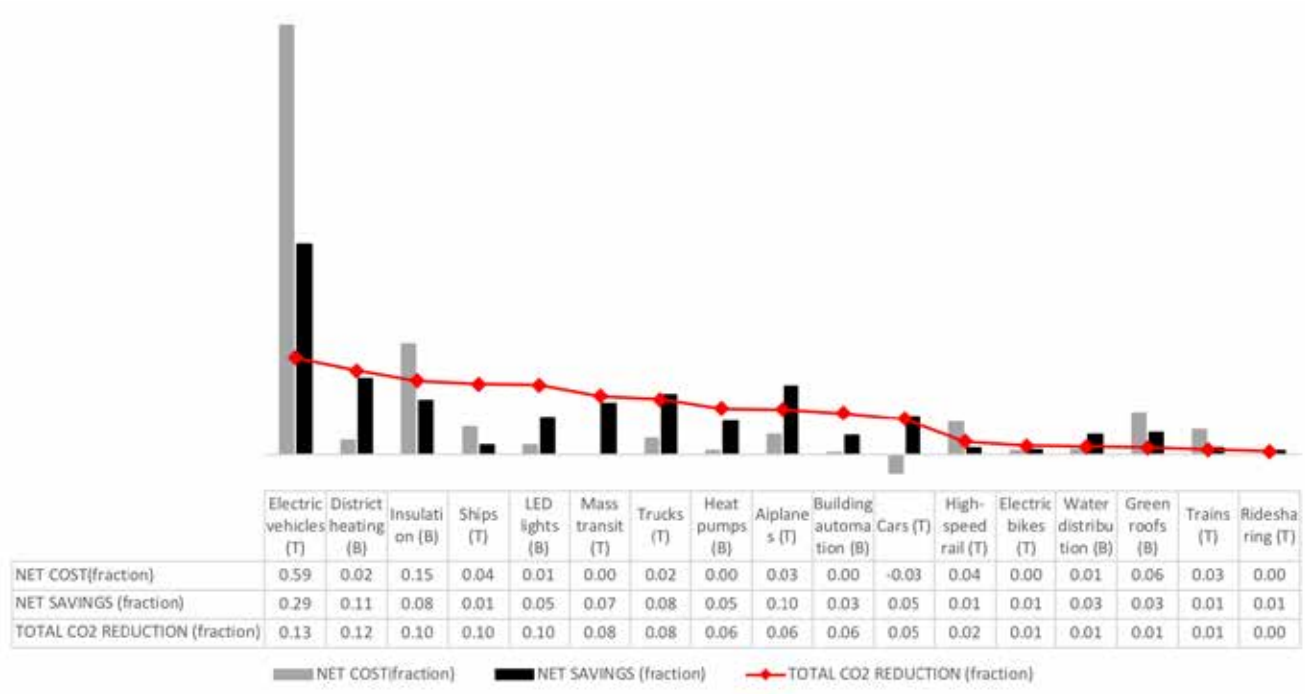


Fig 2 Components of The Project Drawdown



	Electric vehicles (T)	District heating (B)	Insulation (B)	Ships (T)	LED lights (B)	Mass transit (T)	Trucks (T)	Heat pumps (B)	Aiplanes (T)	Building automation (B)	Cars (T)	High-speed rail (T)	Electric bikes (T)	Water distribution (B)	Green roofs (B)	Trains (T)	Ridesharing (T)
NET COST(fraction)	0.59	0.02	0.15	0.04	0.01	0.00	0.02	0.00	0.03	0.00	-0.03	0.04	0.00	0.01	0.06	0.03	0.00
NET SAVINGS (fraction)	0.29	0.11	0.08	0.01	0.05	0.07	0.08	0.05	0.10	0.03	0.05	0.01	0.01	0.03	0.03	0.01	0.01
TOTAL CO2 REDUCTION (fraction)	0.13	0.12	0.10	0.10	0.10	0.08	0.08	0.06	0.06	0.06	0.05	0.02	0.01	0.01	0.01	0.01	0.00

Fig 3 'Drawdown' options for reduction of greenhouse emissions in cities and metropolitan areas (adapted from The Project Drawdown)

For our analysis we selected a sample of the 'drawdown' solutions, which can be applicable for urban environments, which can be divided into two major groups: transport infrastructure (T) and the built environment (B). Their relative contribution to the global decarbonisation budget, upfront costs and savings are presented in Fig 3.

2.3 Retail investors and 'decarboniseable' urban infrastructure elements

There has been a substantial amount of literature covering specifically how infrastructure happened to became such an attractive asset for retail investors, whether it is a better option for growth or income and ascertaining where investors could go for the best infrastructure prospects. The only additional thing we would like to mention here is that the term 'infrastructure' itself still remain extremely ambiguous and can mean different things for different finance actors; and definitions also vary across the countries, e.g., most people can name what 'infrastructure' means in terms of a country's expenditure: roads, rail, schools, healthcare and utilities such as gas or electricity, whilst in the US, infrastructure can even encompass a wall of a building.

However, there is a lot more to the investable infrastructure universe than assets that have traditionally been the purview of public sector involvement. This is partially due to the fact that infrastructure stocks perform slightly differently as compared to other equity markets and can yield different additional opportunities – however, perhaps the most remarkable feature are the regional differences in *where* increased infrastructure spending can reap more benefits and whether investors should be positioned in domestic or global infrastructure stocks. Urban infrastructure from the in-

vestable assets perspective also includes built environments, transit investments, micro-mobility items (such as electric bikes)and many others. And since implementation of decarbonisation strategies and maintenance of subsequent mitigation settings for the broad universe of 'infrastructure assets' can entail substantial business risks, it is important to illustrate how more established trading strategies with use of the Google Trends data can be repurposed to account for these nuanced features in public searches.

3.Results and Impact

As a part of this analysis we extracted three sets of results. The first set comprised specific mapping of the public preferences for various urban infrastructure decarbonisation options across various countries, where only statistically significant results have been included (i.e., excluding the 'low volume searches' option). These options, along with their corresponding countries and cities are presented in Fig 3. This set of results clearly illustrates that the difference between preferred decarbonisation options can be quite remarkable, which can be explained by various factors, notably by the local specificity of the infrastructure type, climatic conditions and some cultural settings, which make people attribute decarbonisation routes only with some particular options. Fig 3 also shows that the built environment has more specificity and selectivity (in public opinion), whilst transport infrastructure has much less marked geographical preferences. Data entries here also show that preferences for decarbonisation options can vary greatly even within countries and across different cities (e.g., in India there is a very strong observable segregation between the preferences for built environment and the transport infrastructure decarbonisation options, which can be used as a clear guidance for investors seeking to invest into urban regeneration and development).

The second set of results was conditioned by the first one, where we aimed to extract a contrasting enough example, with extreme differences between public interests in decarbonisation options within the same country, such as the '*water distribution efficiency*' option in the US. For this specific case study we selected three very different water companies (some non-exhaustive list is also presented here), which have very distinct models of service geo-coverage. All three companies are publicly traded on the New York Stock Exchange, hence we were able to extract financial indicators to relate market sensitivity to the geo-searches. American Water Works ('*AWK*'), Pentair ('*PNR*') and Essential Utilities ('*WTRG*') represent three models of assets geo-coverage: national (present in each state), international (in 30 other countries, in addition to the US) and intra-national (8 states, semi-equally distributed across the country). Illustrations of the dependencies between 'bear-bull' search volume index (SVI) and the weekly prices closures are presented in Fig 4.

water distribution	heat pumps	LED lights	green roofs	e-vehicles	mass transit	e-bikes	country	city
0.00	0.00	0.00	0.00	0.46	0.27	0.27	*Australia*	*Brisbane*
0.00	0.03	0.33	0.00	0.33	0.00	0.31	*Australia*	*Melbourne*
0.00	0.42	0.00	0.00	0.16	0.00	0.42	*Australia*	*Perth*
0.00	0.00	0.00	0.00	0.31	0.19	0.33	*Australia*	*Sydney*
0.23	0.00	0.20	0.00	0.24	0.07	0.26	*Canada*	*Calgary*
0.00	0.00	0.00	0.00	0.21	0.00	0.79	*Canada*	*Halifax*
0.00	0.00	0.00	0.00	0.43	0.00	0.49	*Canada*	*Mississauga*
0.00	0.00	0.49	0.00	0.09	0.00	0.41	*Canada*	*Montreal*
0.00	0.00	0.00	0.00	0.39	0.24	0.37	*Canada*	*Ottawa*
0.00	0.00	0.00	0.00	0.39	0.00	0.61	*Canada*	*Toronto*
0.00	0.00	0.00	0.00	0.65	0.00	0.35	*Canada*	*Vancouver*
0.36	0.00	0.00	0.00	0.25	0.13	0.26	*Costa Rica*	*San Jose*
0.00	0.00	0.35	0.00	0.25	0.10	0.26	*France*	*Paris*
0.00	1.00	0.00	0.00	0.00	0.00	0.00	*Germany*	*Munich*
0.00	0.00	0.00	0.00	0.51	0.12	0.37	*India*	*Ahmedabad*
0.00	0.00	0.39	0.00	0.29	0.00	0.29	*India*	*Bengaluru*
0.00	0.00	0.00	0.00	0.41	0.00	0.59	*India*	*Calcutta*
0.00	0.07	0.00	0.00	0.16	0.00	0.77	*India*	*Chennai*
0.00	0.00	0.00	0.00	0.73	0.00	0.27	*India*	*Coimbatore*
0.00	1.00	0.00	0.00	0.00	0.00	0.00	*India*	*Gurgaon*
0.00	1.00	0.00	0.00	0.00	0.00	0.00	*India*	*Hyderabad*
0.00	0.00	0.00	0.00	1.00	0.00	0.00	*India*	*Indore*
0.18	0.00	0.36	0.00	0.18	0.11	0.16	*India*	*Kochi*
0.36	0.00	0.00	0.00	0.25	0.10	0.29	*India*	*Lucknow*
0.00	0.00	0.00	0.00	0.36	0.30	0.34	*India*	*Mumbai*
0.00	0.00	0.00	0.00	0.41	0.00	0.59	*India*	*New Delhi*
0.00	0.00	0.00	0.00	1.00	0.00	0.00	*India*	*Noida*
0.00	0.00	0.00	0.00	0.54	0.00	0.46	*India*	*Pimpri-Chinchwad*
1.00	0.00	0.00	0.00	0.00	0.00	0.00	*India*	*Pune*
0.06	0.02	0.16	0.12	0.09	0.02	0.22	*India*	*Visakhapatnam*
0.24	0.01	0.28	0.00	0.14	0.08	0.23	*Ireland*	*Dublin*
0.00	0.00	0.00	0.00	0.32	0.27	0.41	*Kenya*	*Nairobi*
0.13	0.01	0.38	0.00	0.09	0.03	0.34	*New Zealand*	*Auckland*
0.00	0.00	0.00	0.00	0.45	0.00	0.55	*New Zealand*	*Christchurch*
0.00	0.00	0.00	0.00	0.57	0.00	0.43	*New Zealand*	*Wellington*
0.00	0.04	0.00	0.00	0.44	0.00	0.49	*Philippines*	*Quezon City*
0.31	0.00	0.18	0.00	0.24	0.11	0.16	*Portugal*	*Lagos*
0.00	0.00	0.00	0.00	0.91	0.09	0.00	*Singapore*	*Singapore*
1.00	0.00	0.00	0.00	0.00	0.00	0.00	*South Korea*	*Seoul*
0.29	0.00	0.15	0.00	0.24	0.14	0.19	*Turkey*	*Istanbul*
0.10	0.01	0.25	0.21	0.14	0.05	0.22	*UK*	*Birmingham*
0.00	0.00	0.00	0.00	0.67	0.00	0.33	*UK*	*Hamilton*
0.00	0.00	0.00	0.00	0.55	0.00	0.45	*UK*	*London*
0.00	0.00	0.00	0.00	0.56	0.00	0.44	*USA*	*Atlanta*
0.00	0.00	0.50	0.00	0.08	0.00	0.42	*USA*	*Austin*
0.00	0.00	0.00	0.00	0.34	0.00	0.60	*USA*	*Boston*
0.00	0.05	0.00	0.00	0.37	0.00	0.58	*USA*	*Charlotte*
0.00	0.00	0.00	0.00	0.63	0.13	0.23	*USA*	*Chicago*
0.00	0.08	0.00	0.00	0.28	0.00	0.63	*USA*	*Dallas*
0.33	0.00	0.00	0.00	0.28	0.15	0.23	*USA*	*Denver*
1.00	0.00	0.00	0.00	0.00	0.00	0.00	*USA*	*Honolulu*
0.00	0.00	0.00	0.00	0.46	0.00	0.49	*USA*	*Houston*
0.00	0.00	0.00	0.00	0.33	0.27	0.40	*USA*	*Irvine*
0.00	0.00	0.00	0.00	0.32	0.12	0.53	*USA*	*Los Angeles*
0.00	0.00	0.00	0.00	0.38	0.00	0.49	*USA*	*Minneapolis*
0.00	0.00	0.00	0.00	0.40	0.00	0.57	*USA*	*New York*
0.00	0.05	0.33	0.00	0.23	0.00	0.38	*USA*	*Philadelphia*
0.00	0.00	0.00	0.00	1.00	0.00	0.00	*USA*	*Phoenix*
0.20	0.00	0.20	0.00	0.32	0.14	0.13	*USA*	*Portland*
0.19	0.01	0.35	0.00	0.09	0.04	0.30	*USA*	*Sacramento*
0.14	0.01	0.16	0.34	0.14	0.05	0.15	*USA*	*San Antonio*
0.00	0.00	0.00	0.00	0.37	0.00	0.59	*USA*	*San Diego*
0.00	0.00	0.00	0.00	0.31	0.10	0.59	*USA*	*San Francisco*
0.00	0.07	0.00	0.00	0.50	0.00	0.37	*USA*	*Seattle*
0.00	1.00	0.00	0.00	0.00	0.00	0.00	*USA*	*Washington*

Fig 3 'Drawdown' options prevalence in the global public Google Trends searches, mapped against corresponding cities and countries

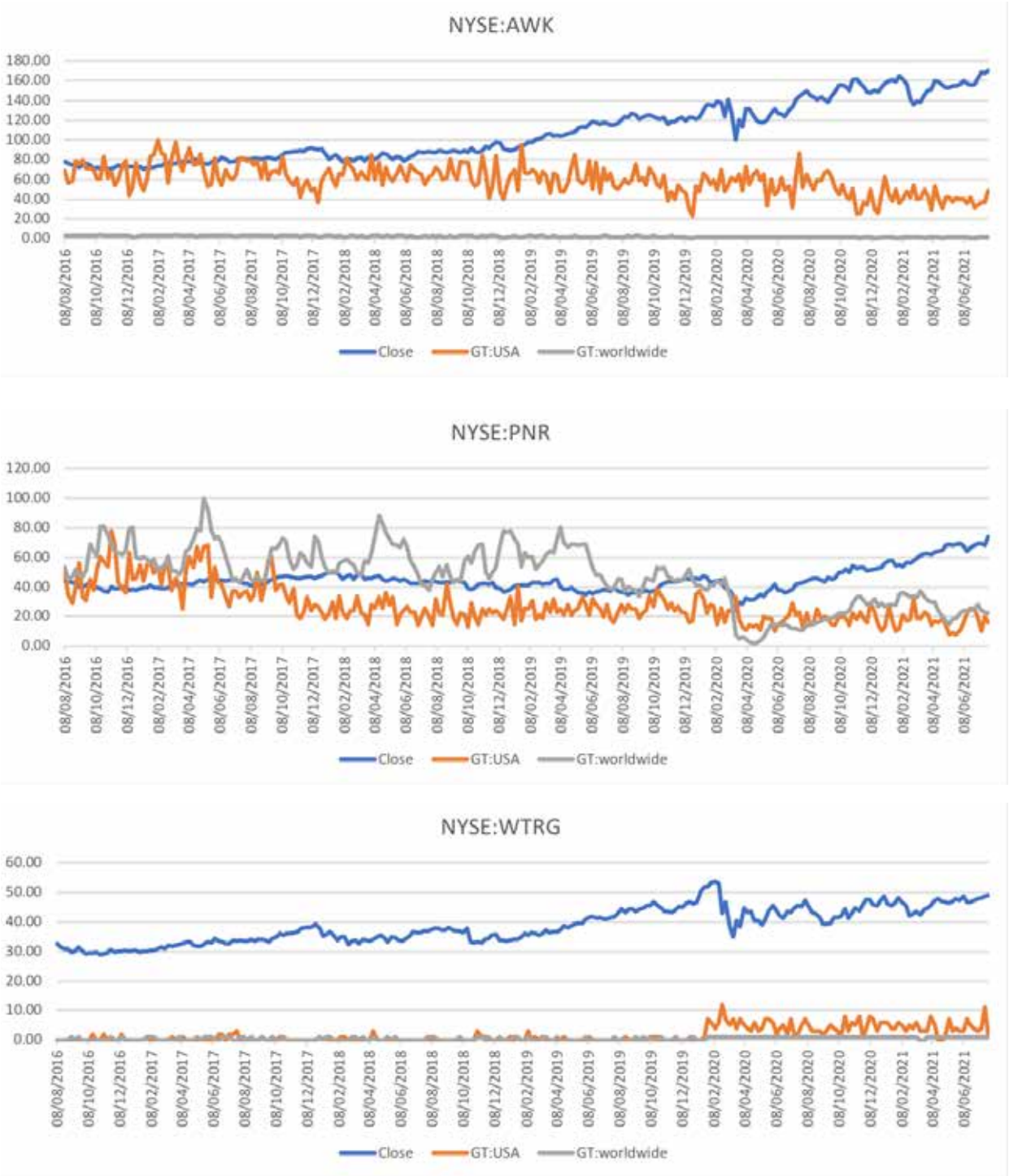


Fig 4 American Water Works (NYSE:AWK), Pentair (NYSE:PNR) and Essential Utilities (NYSE:WTRG), which represent: (TOP) the largest publicly-listed company in the US, which provides drinking water and wastewater services to 46 states; (MIDDLE) global US-listed business, operating in 30 countries; and (BOTTOM) water utility/wastewater service company, operating in 8 US states only

Illustrations of the dependencies between 'bearish' and 'bullish' search volumes and the weekly price closures are presented in Fig 4. Results demonstrated some strong 'regional' effect of the search patterns for the companies, operating within narrower geographies (strength of the observable market moves prediction decreases from '*WTRG*' to '*AWK*' to '*PNR*'). Thus, the strength of statistical relationship between search term '*water distribution efficiency*' and the company ticker on the global scale decreases from '*WTRG*' (0.062**) to '*AWK*' | '*PNR*' (-0.039-(-0.034)), whilst on the regional (i.e., US market only) level the strength of relationships is stronger across all three companies, and varies from 0.01** for '*WTRG*' | *'water distribution efficiency'* up to 0.1*** for '*AWK*' | *'water distribution efficiency'*. These numbers also confirmed the importance of geography in differentiated search volumes analytics for infrastructure traders.

Finally, when these strength dependencies between the market moves and the public interest in decarbonisation options have been established, we looked into which companies are more active in implementing decarbonisation options across the assets using geographical proxy factors. According toEssential Utilities Group operates across 8 US states (Pennsylvania, Ohio, N Carolina, Illinois, Texas, New Jersey, Indiana and Virginia), so we looked into public interest on the web maps across searches for company names and decarbonisation options (i.e., 'water distribution efficiency'). These keywords (Fig 5) illustrate fractions of the country, covered by both companies, hence suggesting where implementation of this decarbonisation option will likely have statistically significant material effect.

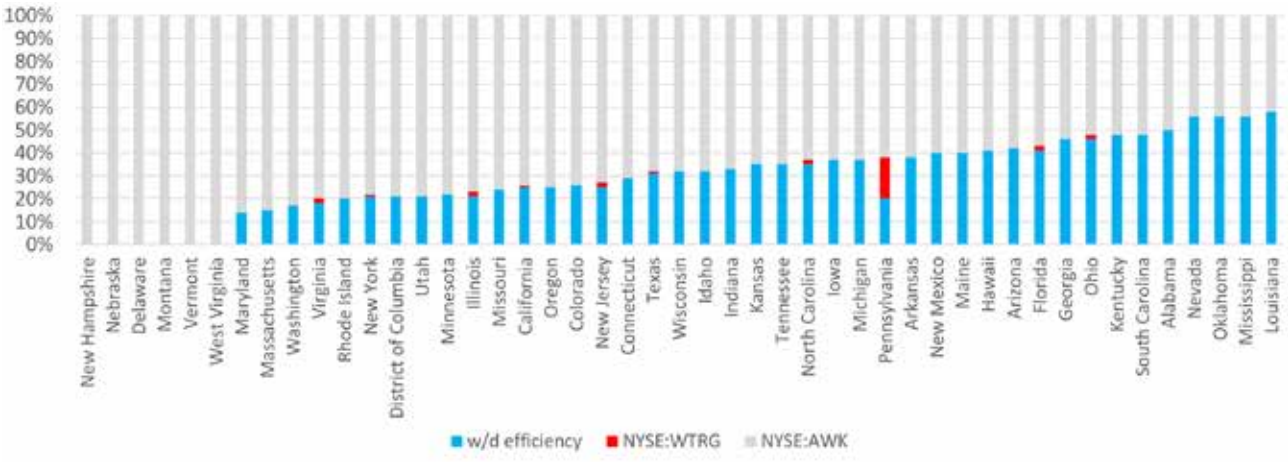


Fig 5 Relation proportions of the SVI rates on the Google Trends for two major water infrastructure providers across 46 US states, and their relation to the public interest in water distribution efficiency as urban infrastructure decarbonisation option

4.Lessons

This first exploratory data analysis on the glowing role of the individual investors' presence in urban decarbonisation process around the world demonstrated that:

- The theoretical knowledge on the growing presence of retail investors in sustainable urban infrastructure can be confirmed empirically;
- Decarbonisation options have a very strong attribute of the social preference attached to them, which should be accounted for;
- Types of infrastructure companies, which can be attractive for direct investments, have their own specific spatial characteristics.

5.Conclusion

The findings of this study can help to conclude that the growing role of 'big data', which allows for increase in the speed of funding flows circulation and decrease transaction costs can be also instrumental in designing future complex financial instruments, which would cover not only the problem of the balance of costs, but also of the speed of the project implementation, which is the crucial aspect when trying to bring the planetary temperature down.

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Comprehensive evaluation of urban sustainable development in Hainan China: Based on the united nations sustainable development goals

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1.Introduction

Over the past few decades, the world has been in the process of rapid urbanization. In 1950, only 30% of the world's population lived in cities. By 2018, this proportion increased to 55% and is expected to increase to 68% in 2050 (United Nations, 2018). Although urban areas account for less than 1% of global land coverage, they contribute 75% of global GDP, consume 60-80% of energy, and generate 75% of global waste and carbon emissions (Thomas et al., 2019). Accompanying rapid urbanization, extreme weather events such as urban waterlogging and high temperatures have occurred frequently, pollution has increased, and the greenhouse effect has increased, which has brought severe challenges to improving urban resilience, achieving carbon neutrality goals, and responding to climate change crises.

In order to measure, monitor, and report on the sustainable development of cities, the United Nations proposed 17 Sustainable Development Goals (SDGs) covering the three dimensions of economy, society, and environment in the *2030 Agenda for Sustainable Development* in 2015 (UN, 2015), Sustainable Development Goal 11 (SDG 11), "Building inclusive, safe, resilient and sustainable cities and human settlements", is critical to achieving all the other SDGs (Acuto et al., 2018). The SDGs can be broken down into 169 specific targets, and SDG 11 includes seven technical targets and three policy targets, with a total of 15 measurable indicators of progress of those targets. Among these indicators, as of March 29, 2021, ten indicators are facing data missing in monitoring and evaluation; and one indicator was temporarily removed with no suitable substitute. In addition, SDG 11 is linked to at least 11 other SDGs, and about one-third of the more than 230 SDG indicators can be measured at the city level (UN-Habitat, 2019). In order to achieve the goals of sustainable urban development, the Third United Nations Conference on Housing and Sustainable Urban Development adopted the *New Urban Agenda* (Habitat III, 2016), a framework document for sustainable urban development in the next 20 years, in October 2016. The *UN Global Sustainable Development Report 2019* proposes six entry points and four levers to be deployed coherently through each entry point to achieve the transformation required by the *UN 2030 Agenda for Sustainable Development* (Messerli and Murniningtyas, 2019; Sachs et al., 2019a). "Urban and suburban development" is one of the most important entry points, which highlights the direction of transformation for the realization of SDG 11 in

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the future. In 2016, China formulated the *National Plan for the Implementation of the 2030 Agenda for Sustainable Development*, and issued the *Plan for the Construction of Innovation Demonstration Zones for the Implementation of the 2030 Agenda.* So far, these zones for demonstrating innovative sustainable development have been established in Shenzhen, Taiyuan, Guilin, Chenzhou, Lincang, and Chengde. SDG13 advocates urgent action to deal with climate change and its impact, including 3 technical targets and two policy targets, totaling eight indicators. Carbon neutrality requires the joint support of 17 SDGs, such as taking a green development path, reducing greenhouse gas emissions, developing a circular economy, and reducing energy consumption. At the same time, the 17 SDGs need to be driven by carbon neutrality. Support each other.

At present, the monitoring, comprehensive evaluation, and application of the United Nations' SDG indicators have become an international research frontier. The United Nations, national government departments, international organizations, and research institutes in China and elsewhere have carried out monitoring and comprehensive assessments of urban sustainable development indicators using statistical data. For example, experts from the Sustainable Development Solution Network (SDSN) carried out a comprehensive urban sustainability assessment for 45 European capital cities and 105 large American cities (Guillaume et al., 2019; Lynch et al., 2019); Xu et al. (2020) used statistical data to comprehensively evaluate sustainable development at the national and provincial levels in China by focusing on 17 goals and 119 indicators

from temporal and spatial dimensions. Xu et al. (2019) conducted a comprehensive assessment of the sustainable development of 27 cities in China's Yangtze River Delta urban agglomeration using SDG 11 indicators. However, the above studies were mainly based on statistical data, which could not effectively reveal the spatial and temporal patterns and differences of SDG 11 indicators. Under the Technology Promotion Mechanism, the United Nations has proposed to promote the global implementation of the 2030 Agenda through scientific and technological innovation. As an important aspect of this, the United Nations emphasizes the use of mass sources of big data and technologies such as Earth observation and geographic information to carry out quantitative monitoring and evaluation of SDGs. The Earth Observation Satellites Committee (CEOS) and the intergovernmental Group on Earth Observations (GEO) have used Earth observation technologies and methods to support SDGs (Anderson et al., 2017; Paganini and Petiteville, 2018; Kavvada et al., 2020). Based on "Earth Big Data Science Project" of the Chinese Academy of Sciences, Guo et al. (2021) monitored and evaluated SDG indicators by focusing on six SDGs and using “big Earth data” technology and methods (Guo 2019); Chen et al. (2019) studied and proposed a comprehensive assessment method combining statistics and geographic information to quantitatively and comprehensively assess the implementation of the 2030 Agenda in Deqing County, Zhejiang Province. At present, most studies are using Earth observation, statistics, and other big data to carry out global or national monitoring and measurement of a single SDG indicator, while few studies monitor and comprehensively evaluate multiple SDG indicators at the provincial, city, and county levels (Jiang et al., 2021).). Nerini et al. (2019) analyzed the relationship between SDG 13 climate change and the other 17 SDGs, and pointed out that climate change has a destructive effect on the 16 SDG goals, and the successful response to climate change will help achieve the 17 SDGs. But it hinders the implementation of SDG12 goals (Nerini et al., 2019).

This paper takes Hainan Province as the research area, using earth observations, statistics, and other public sources to monitor and comprehensively evaluate SDG indicators at the city and county scale to better support the realization of the carbon neutral target. In 2018, the Chinese government proposed the construction of the Hainan Free Trade Port and released an overall plan for construction in 2020. In the "14th Five-Year Plan" of Hainan Province, it is clearly stated that it will be the first to achieve carbon peak in 2025 and strive to achieve carbon neutrality in 2050. Therefore, focusing on the relevant indicators of SDG 11 and SDG 13 and carrying out a comprehensive assessment of urban sustainable development in Hainan Province is of great significance, and it is also a national strategic demand. This paper adds disaster and greenhouse gas indicators in the SDG 13 on the basis of the SDG 11 indicator framework system, and mainly carries out: (1) The construction of a localized system based on SDG 11 indicators in Hainan Province, focusing on the analysis of the impact of urbanization on carbon emissions; (2) quantitative and systematic monitoring and comprehensive assessment of SDG11 indicators at the municipal and county level of Hainan Province from 2010 to 2018

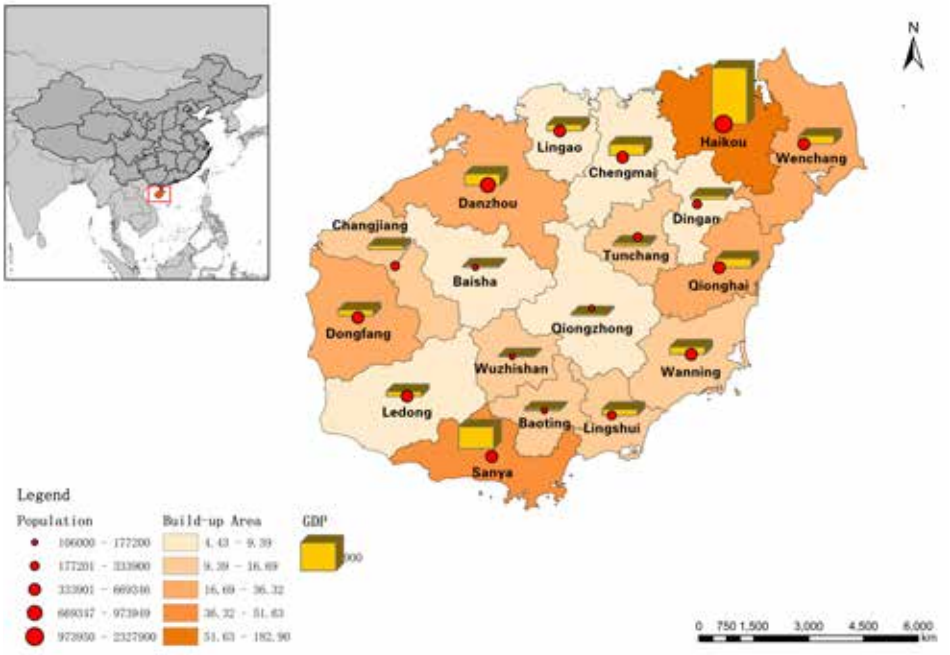


Figure 1 Study area

based on Earth observation, statistics, and other data sources. The goal is to provide approaches and solutions for other provinces and regions to implement the United Nations Sustainable Development Goals.

2.Research area and data

2.1 Overview of the study area

Hainan (E108°37′~111°03′, N18°10′~20°10′ N) is in the southernmost part of China. The province has a total land area of 35,400 square kilometers and a sea area of about 2 million square kilometers. This research area includes three prefecture-level cities, five county-level cities, four counties, and six minority autonomous counties in Hainan Province, but excludes Sansha City, a total of 18 cities and counties (as shown in Figure 1).

Rapid urbanization has led to a continuous increase in the urban population, which has brought many challenges to the urbanization of Hainan Province. For example, the total water supply in Hainan Province's cities rose from 314.25 million cubic meters in 2005 to 61.452 million cubic meters in 2018. Domestic waste in Hainan Province increased from 1.15 million tons in 2005 to 2.5721 million tons in 2018, which is bound to bring huge challenges to urban water supply and garbage disposal (Hainan Provincial Bureau of Statistics, 2019); compared to the urban per capita in Hainan in 2014 The park green area is 12.1 square meters, and the per capita park green area in the city fell to 9.96 square meters in 2018 (Hainan Provincial Bureau of Statistics, 2019). The ever-increasing urban population has brought many problems to the planning of urban public spaces, especially in the re-planning of the old city. Therefore, unplanned urban expansion in the context of the province's urbanization has made the urban ecological environment relatively fragile and the ecological security situation is very severe (Liang et al., 2015; Shi et al., 2009).

2.2 Dataset used

SDG11, "Sustainable Cities and Communities", includes 10 specific goals and 15 indicators according to the *United Nations Statistical Commission* in the *2030 Agenda for Sustainable Development*. The indicators are related to housing, transportation, land use efficiency, heritage protection, urban environments, and public open space (UN, 2015). Considering the actual situation of Hainan Province,

Table 1 Data related to SDGs used in the study

Localized indicators	Data	Temporal interval	Data sources
11.1.1—The proportion of people enjoying the minimum living security (-)	Number of subsistence allowances	2010-2018	Statistical data (https://www.hainan.gov.cn/hainan/zfsj/xsj.shtml)
11.2.1—Annual passenger volume (+)	Passenger volume	2010、2015、2020	Statistical data (http://stats.hainan.gov.cn/tjj/)
11.3.1—The ratio between land use rate and population growth rate (+)	Urban population and urban built-up area	2010、2015、2020	Remote sensing data (Landsat, Worldpop, Sentinel)
11.5.1—Fertility rate (-)	Total population of the city and the number of victims	2010-2018	Statistical data (https://www.hainan.gov.cn/hainan/zfsj/xsj.shtml)
11.5.1/13.1.1—Rate of dead and missing (-)	Total population of the city and the number of dead and missing	2010-2018	Statistical data (https://www.hainan.gov.cn/hainan/zfsj/xsj.shtml)
11.5.2/13.1.2—direct economic losses as a proportion of GDP (-)	GDP and direct economic loss in disasters	2010-2018	Statistical data (https://www.hainan.gov.cn/hainan/zfsj/xsj.shtml)
11.6.1—Domestic garbage removal and transportation volume (+)	Domestic garbage clearance volume	2010-2018	Statistical data (https://www.hainan.gov.cn/hainan/zfsj/xsj.shtml)
11.6.2—$PM_{2.5}$ concentration (-)	$PM_{2.5}$ remote sensing data	2010-2018	Remote sensing data (AOD) (http://fizz.phys.dal.ca/~atmos/martin/?page_id=140)
13.2.2—CO_2 emissions (-)	CO_2 emissions	1997-2017	Surface monitoring data
13.2.2—NO_2 concentration (-)	NO_2 concentration	2010-2018	Statistical data (http://stats.hainan.gov.cn/tjj/)
13.2.2—SO_2 concentration (-)	SO_2 concentration	2010-2018	Statistical data (http://stats.hainan.gov.cn/tjj/)
11.7.1—Park green area per capita (+)	Per capita Park green area	2010-2018	Statistical data (http://stats.hainan.gov.cn/tjj/)

however, the quantity of relevant data and the evaluation method cannot match these indicators completely. Therefore, it is necessary to adopt reliable, high-quality data applicable to the local situation of Hainan Province to localize the SDG 11 indicators. On this basis, we increased the disaster and greenhouse gas indicators in the SDG 13 climate action, and carried out a comprehensive assessment of the sustainable development of cities in Hainan Province. This study mainly adopts statistics, Earth observation, and ground observation data, and the time scale is from 2010 to 2018 (Table 1).

SDG11 indicators (United Nations, 2018)	Localized indicators	Method
11.1.1 Proportion of urban population living in slums, informal settlements or inadequate housing	Rate of subsistence allowances	$X_1 = \frac{Number\ of\ subsistence\ allowances}{Total\ population} \times 100\%$
11.2.1 Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities	Passenger volume	Statistics
11.3.1 Ratio of land consumption rate to population growth rate	Ratio of land consumption rate to population growth rate	$X_3 = LCRPGR = \frac{\ln(Urb_{t+n}/Urb_t)}{\ln(Pop_{t+n}/Pop_t)} \times 100\%$
11.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	Fertility rate	$X_4 = \frac{Number\ of\ victims}{Total\ population} \times 100\%$
	Rate of dead and missing	$X_5 = \frac{Number\ of\ dead\ and\ missing}{Total\ population} \times 100\%$
11.5.2 Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters	Direct economic loss in disasters to global GDP	$X_6 = \frac{Direct\ economic\ loss\ in\ disasters}{GDP} \times 100\%$
13.2.2 Total greenhouse gas emissions per year	(9) CO_2 emissions	CO_2 emissions data is based on authoritative provincial accounting data combined with DMSP/OLS and NPP/VIIRS data, and particle swarm optimization-backpropagation (PSO-BP) algorithm is adopted to reverse the performance of 18 cities in Hainan Province from 2010 to 2017. CO_2 emissions in the county (Chen et al., 2020a, Wu et al., 2016; Chen et al., 2020b).
	NO_2 concentration	Statistics
	SO_2 concentration	Statistics
11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities	Per capita Park green area	Statistics

LCRPGR represents the ratio of land use rate to population growth rate, Urb_t represents the area of the urban area built in the past as the initial value, Urb represents the area after n years of urban expansion, as the final value, Pop_t represents the number of the city's population in the past as the initial value, Pop_{t+n} represents the number after n years of urban population growth as the final value.

Table 2 SDGs indicator system construction and localization methods in Hainan Province

Note: +(-)means the higher (lower) the indicator, the better the level for sustainability.

3.Construction and research method of the index system

3.1 The construction of the index system and the localization processing method

Due to the different administrative levels of the study area, some data cannot be used directly, and necessary data processing is required to apply to each city and county and match the sustainable development indicators proposed by the United Nations Statistical Commission. The data processing method is shown in Table 2.

3.2 Comprehensive evaluation method

The comprehensive assessment of urban sustainable development mainly includes three steps: (I) select the extreme value of data and obtain a single index score through normalization, build a single indicator dashboard and trend chart, and (III) calculate the city's comprehensive sustainable development score.

3.2.1 Normalization of data

Due to the different city scales, some data are different in order of magnitude. To ensure the comparability of these data, the influence of outliers in the data on the result, it is necessary to remove the extremely anomalous or extremely small data in the data list. The average value of the top three data is regarded as the upper bound of the index, and the average value of the bottom three data values is regarded as the lower bound of the index. In order to make the data comparable between the indicators and increase the visibility of the indicators, each data will get a score in the range of [0,100], where, 0 means the lowest level of sustainable development, and 100 represents the best level of sustainable development.

After the upper and lower bounds are determined, the higher the index is, the higher the sustainability is. Normalized Formula (1) is used to transform the data [0,100], and a single index score is obtained:

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}} \times 100 \quad (1)$$

Where, x is the original data; x_{max} / x_{min} respectively represent the upper and lower bounds of the data, and x' represents the normalized value after scaling, that is, the single index score.

If the larger the index is, the lower the sustainability is, then the normalized Formula (2) is used to transform the data [0,100] to get a single index score:

$$x' = 100 - \frac{x - x_{min}}{x_{max} - x_{min}} \times 100 \quad (2)$$

where, x is the original data; x_{max} / x_{min} respectively represent the upper and lower bounds of the data, and x' represents the normalized value after scaling, that is, the single index score.

3.2.2 Dashboard building method

In order to better distinguish the degree of development of the city's single indicators, a dashboard like the "traffic indicator" is introduced (Sachs et al., 2019b). Its purpose is to use "green, yellow, orange, and red" to replace the scores of indicators, highlighting the need for each city to pay special attention to the indicators with poor development, so as to remind relevant departments to prioritize their optimization and improvement measures for the indicators.

To better show the trend of a single indicator over a long period of time, we introduce the same approach as above to build the dashboard trend chart. Specifically, we calculated the growth rate of each index. If the larger the index, the higher the sustainability, then the growth rate Formula (3) can obtain the growth rate:

$$X_{GR} = (\frac{x}{x_n})^{\frac{1}{n-1}} \times 100\% \quad (3)$$

where, X_{GR} is the growth rate, x is the data value of the year, and x_n is the data value n years ago.

If the larger the index, the lower the sustainability, then use the growth rate Formula (4) to get the growth rate:

$$X_{GR} = (\frac{x_n}{x})^{\frac{1}{n}} \times 100\% \quad (4)$$

where, X_{GR} is the growth rate, x is the data value of the year, and x_n is the data value n

	Substantial progress/on track	Fair progress but acceleration needed	Limited or no progress	Deterioration
11.1.1	$x \geq 0.2$	$0.1 \leq x < 0.2$	$0 \leq x < 0.1$	$x < 0$
11.2.1	$x \geq 0.3$	$0.1 \leq x < 0.3$	$0 \leq x < 0.1$	$x < 0$
11.3.1	$x \geq 0.2$	$0.05 \leq x < 0.2$	$0.05 \leq x < -0.05$	$x < -0.05$
11.5.1	$x \geq 0.5$	$0.1 \leq x < 0.5$	$0 \leq x < 0.1$	$x < 0$
11.5.2	$x \geq 1$	$0.5 \leq x < 1$	$0 \leq x < 0.5$	$x < 0$
11.6.1	$x \geq 0.1$	$0.05 \leq x < 1$	$-0.05 \leq x < 0.05$	$x < -0.05$
11.6.2	$x \geq 0.01$	$0 \leq x < 0.01$	$-0.01 \leq x < 0$	$x < -0.01$
11.7.1	$x \geq 0.1$	$0.05 \leq x < 0.1$	$-0.05 \leq x < 0.05$	$x < -0.05$

Table 2. Classification threshold for the trend of each indicator

years ago.

After the growth rate of each indicator is obtained, the abnormal value in the growth rate is eliminated, and the average value of the top three growth rates is used as the upper bound, and the lower bound is 0. Use formula (5) to get the normalized growth rate score, the range is [-1,3].

$$GR' = \frac{GR - 0}{GR_{max} - 0} \times 3 \quad \textbf{(5)}$$

If the denominator is 0 in the calculation of the trend index, the trend index value is determined in three cases: if the numerator is positive, the trend index value is 3; if the numerator is 0, the trend index value is 0; and if the numerator is negative the trend index is -1.

In consultation with experts, the indicators were divided into four levels, as shown in Table 2.

3.2.3 Comprehensive City Assessment

A single indicator evaluation alone cannot fully show the sustainable development level of a city. A city's comprehensive score is needed to evaluate the city's relative sustainable development level. All indicators are given equal weights, and the average of all indicators for each city in each year is calculated to obtain the city's comprehensive score.

$$X' = \frac{\sum_i^n x'_i}{n} \quad \textbf{(6)}$$

where n is the total number of indicators and x'_i is the score of a single indicator.

4.Analysis

4.1 Single indicator analysis

As shown in Figure 2, Sanya City has the largest number of "green indicators". Domestic waste and per capita green area are higher than most cities and counties each year; Haikou's ranking of indicators for development is relatively stable, with low insurance rate, passenger transport volume and solids. Garbage is ahead of most cities and counties; Changjiang County and Ledong had the largest number of "red indicators" in 2010, Qiongzhong had the largest number of "red indicators" in 2015, and Dingan and Qiongzhong had the largest number of "red indicators" in 2018 "The largest number.

Figure 2 Single index score dashboard of cities in Hainan in 2010, 2015, and 2018 The indexes corresponding to the horizontal axis are: No. 1: the proportion of people enjoying the minimum living security; No. 2: annual passenger traffic; No. 3: land utilization; No. 4: population disaster rate; No. 5: direct economy Loss as a percentage of GDP; No.6: Domestic waste removal and transportation; No.7: Air quality ($PM_{2.5}$, CO_2, SO_2, NO_2); No.8: Per capita Park green area.

Figure 3 Single index progress chart of cities in Hainan in 2018. The indexes corresponding to the horizontal axis are: No. 1: the proportion of people enjoying the minimum living security; No. 2: annual passenger traffic; No. 3: land utilization; No. 4: population disaster rate; No. 5: direct economy Loss as a percentage of GDP; No.6: Domestic waste removal and transportation; No.7: Air quality ($PM_{2.5}$, CO_2, SO_2, NO_2); No.8: Per capita Park green area.

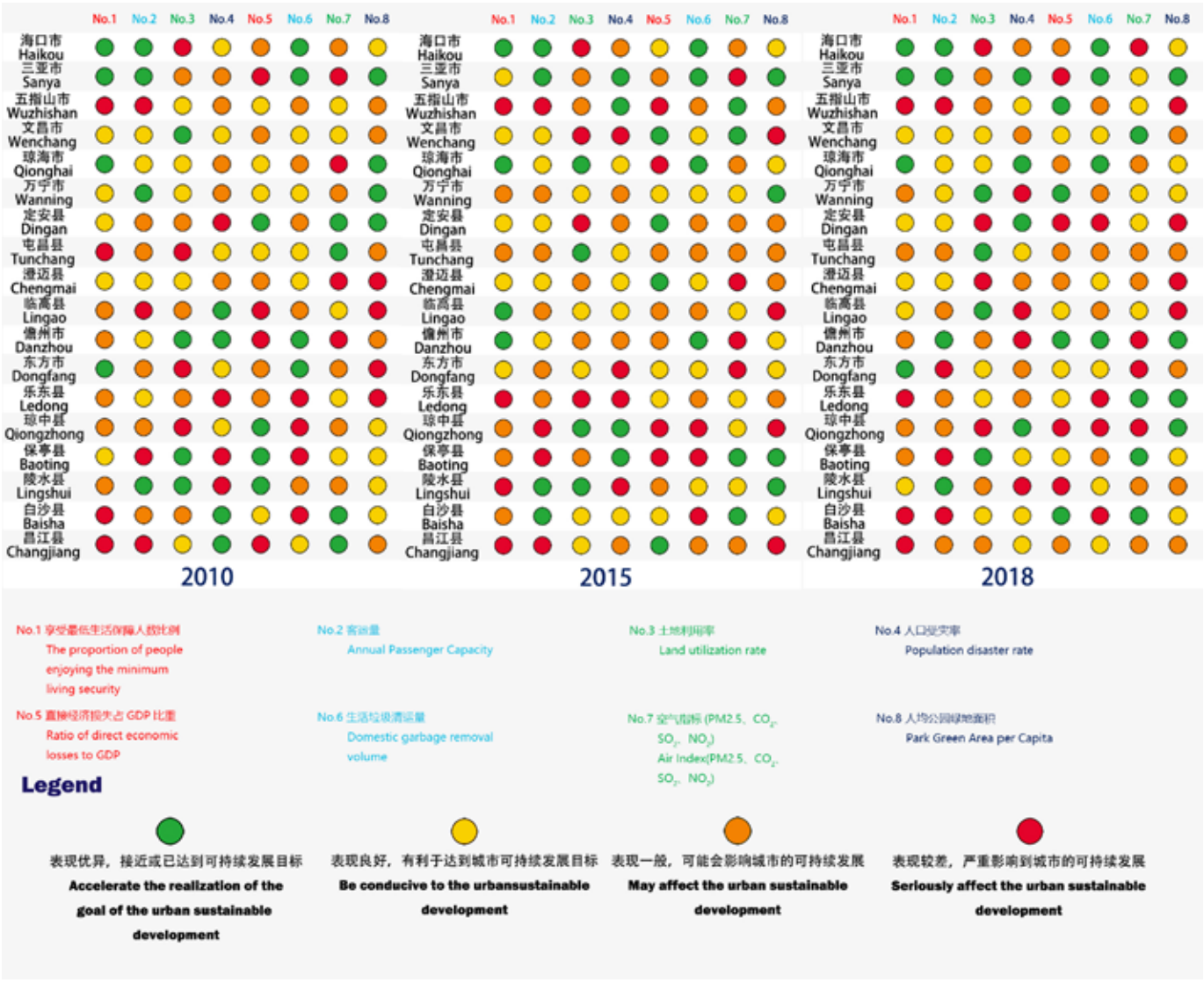


Figure 2 Single index score dashboard of cities in Hainan in 2010, 2015, and 2018 The indexes corresponding to the horizontal axis are: No. 1: the proportion of people enjoying the minimum living security; No. 2: annual passenger traffic; No. 3: land utilization; No. 4: population disaster rate; No. 5: direct economy Loss as a percentage of GDP; No.6: Domestic waste removal and transportation; No.7: Air quality (PM2.5, CO_2, SO_2, NO_2); No.8: Per capita Park green area.

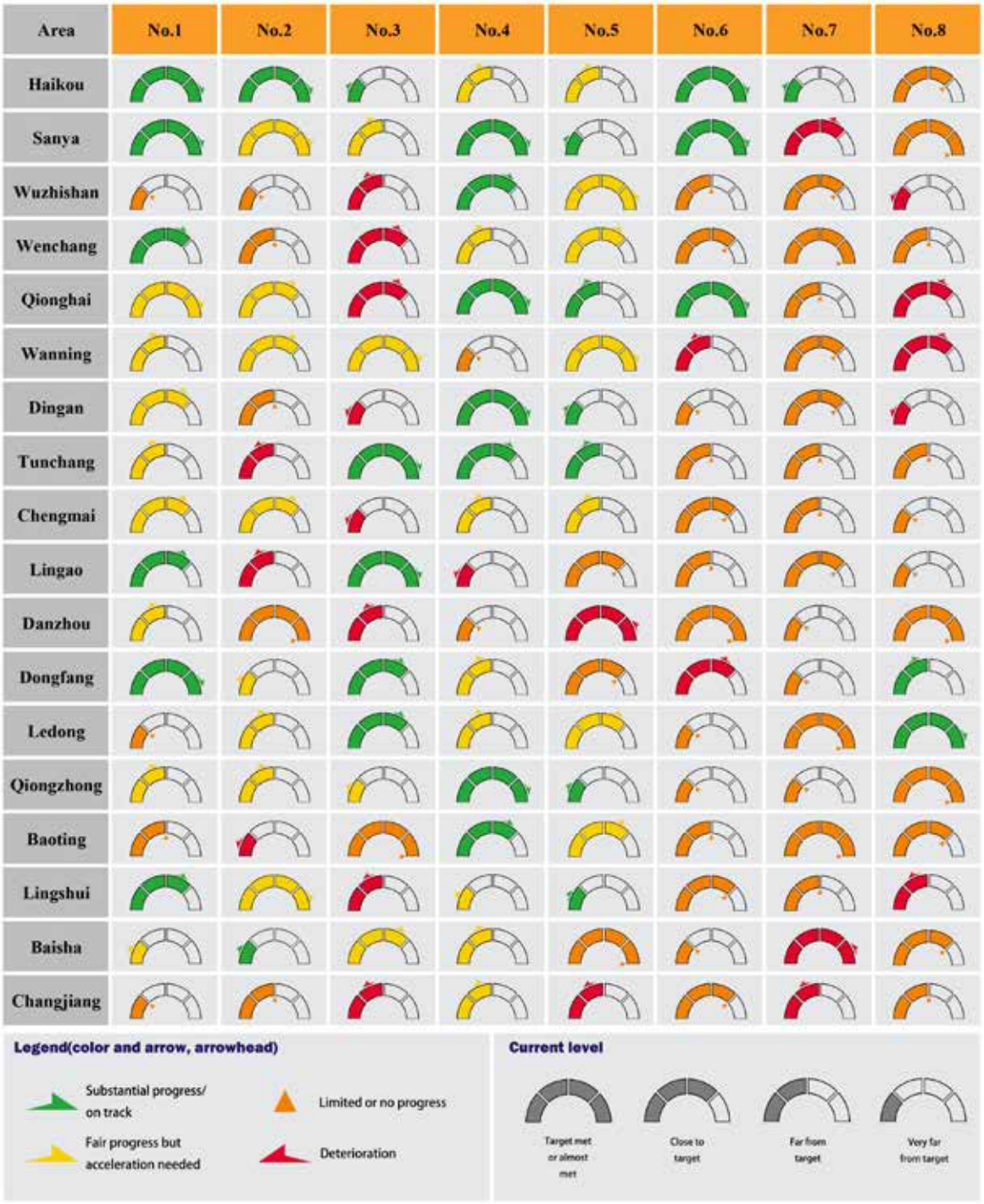


Figure 3 Single index progress chart of cities in Hainan in 2018. The indexes corresponding to the horizontal axis are: No. 1: the proportion of people enjoying the minimum living security; No. 2: annual passenger traffic; No. 3: land utilization; No. 4: population disaster rate; No. 5: direct economy Loss as a percentage of GDP; No.6: Domestic waste removal and transportation; No.7: Air quality (PM2.5, CO_2, SO_2, NO_2); No.8: Per capita Park green area.

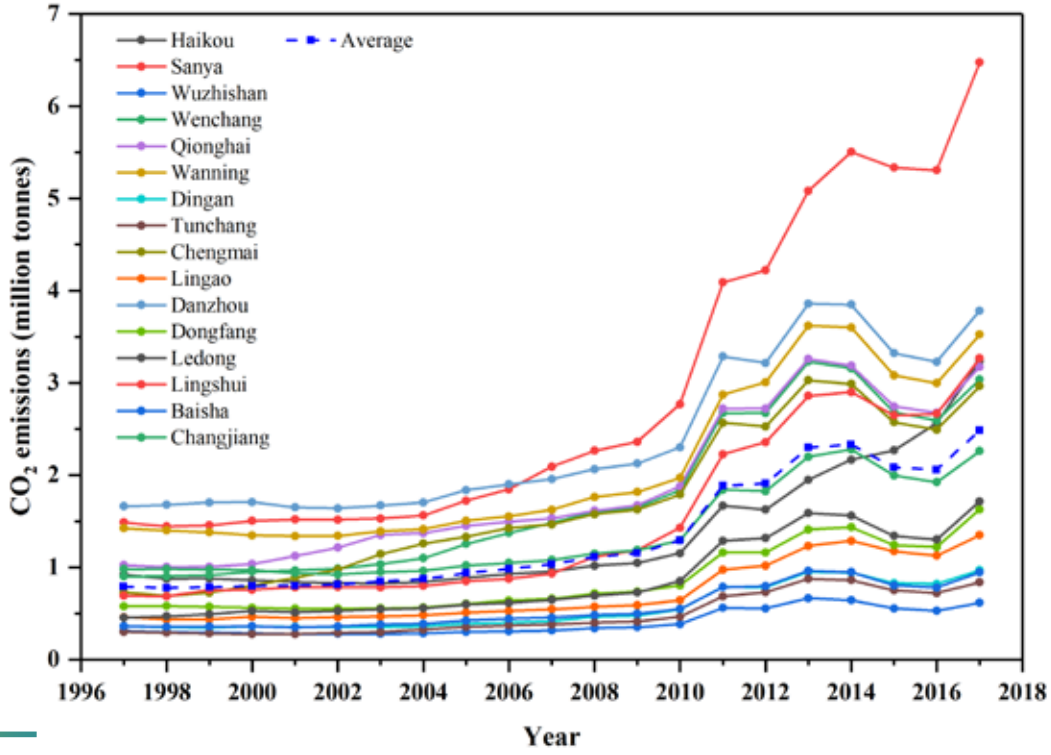
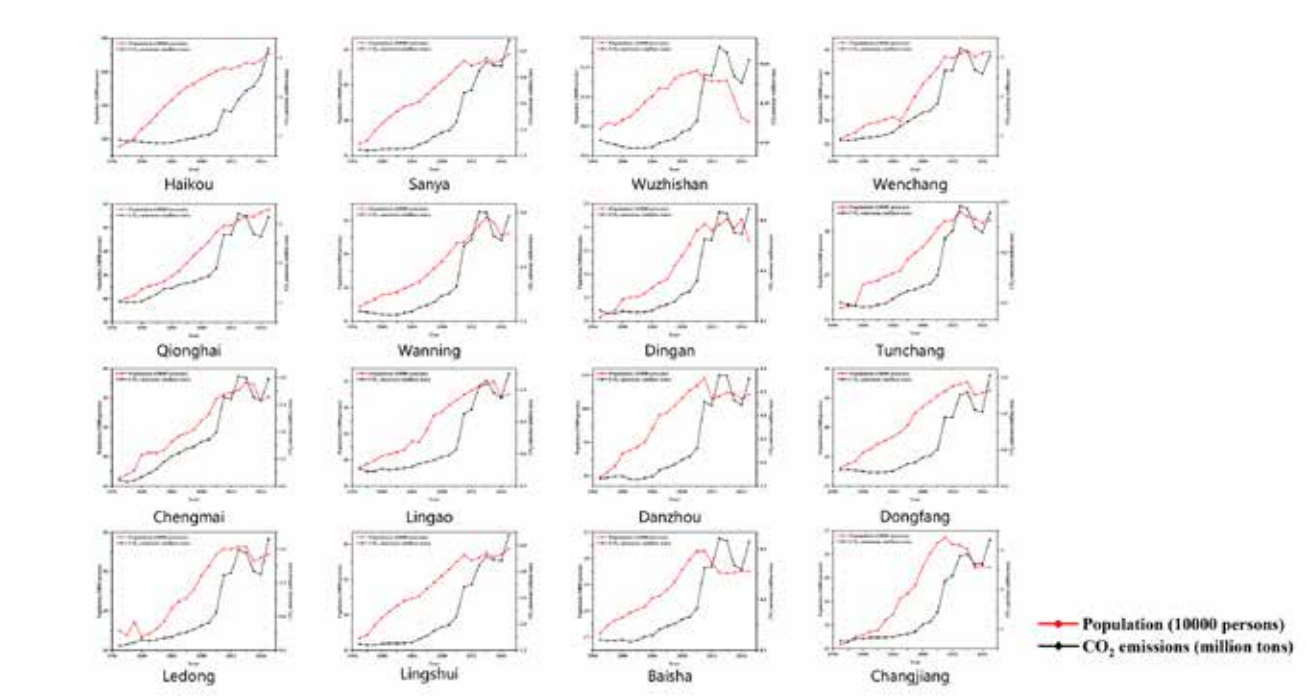


Figure 4 CO_2 emission in each administrative region of Hainan Province from 1997 to 2017

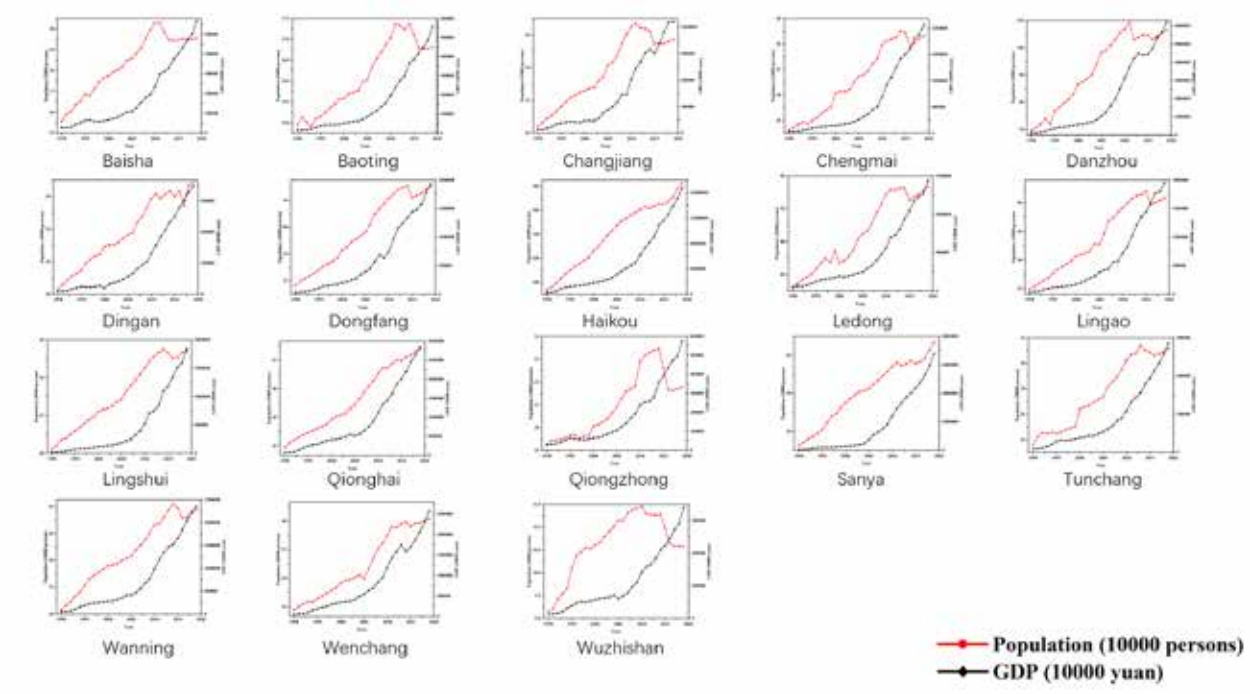
From the city-level perspective, the change trends of Hainan's main indicators are mainly as follows (Figure 3). (1) Haikou and Sanya are in the middle stage of sustainable development. Rapid urbanization drives the development of various industries, such as transportation and industry. As a pilot city of national environment programs and tourism, Haikou and Sanya are still maintaining the development of environmental indicators while developing their economy. (2) The cities and counties, led by Lingao County, are in the early stage of sustainable development, and all the indicators show an upward trend except the environmental indicators. (3) Wanning City and Danzhou City are leading the cities and counties in the middle and early stages of sustainable development, and the development trend of each index fluctuates greatly. In general, after the 13th Five-Year Plan, the development trend of all indicators has improved, especially the environmental indicators, including air quality, per capita park green space area, and gas emissions, which are closer to the sustainable development goals.

As shown in Figure 4, CO_2 emissions in all administrative regions of Hainan Province were relatively stable before 2010, and then increased sharply after 2010. After 2013, the growth rate slowed down again in most administrative regions, while the growth rate in Sanya and Haikou continued to increase. The CO_2 emission of Baisha County is the lowest, and the CO_2 emission of Sanya s is much higher than that of other cities and counties after 2010.

Figure 5 shows the comparative analysis of CO_2 emissions, GDP and population. The population growth of most administrative regions slowed down gradually from 2010, and the population of Qionghai and Wanning began to decline around 2015. Meanwhile, the increasing speed of population decreases while CO_2 emission and GDP keep increasing rapidly.



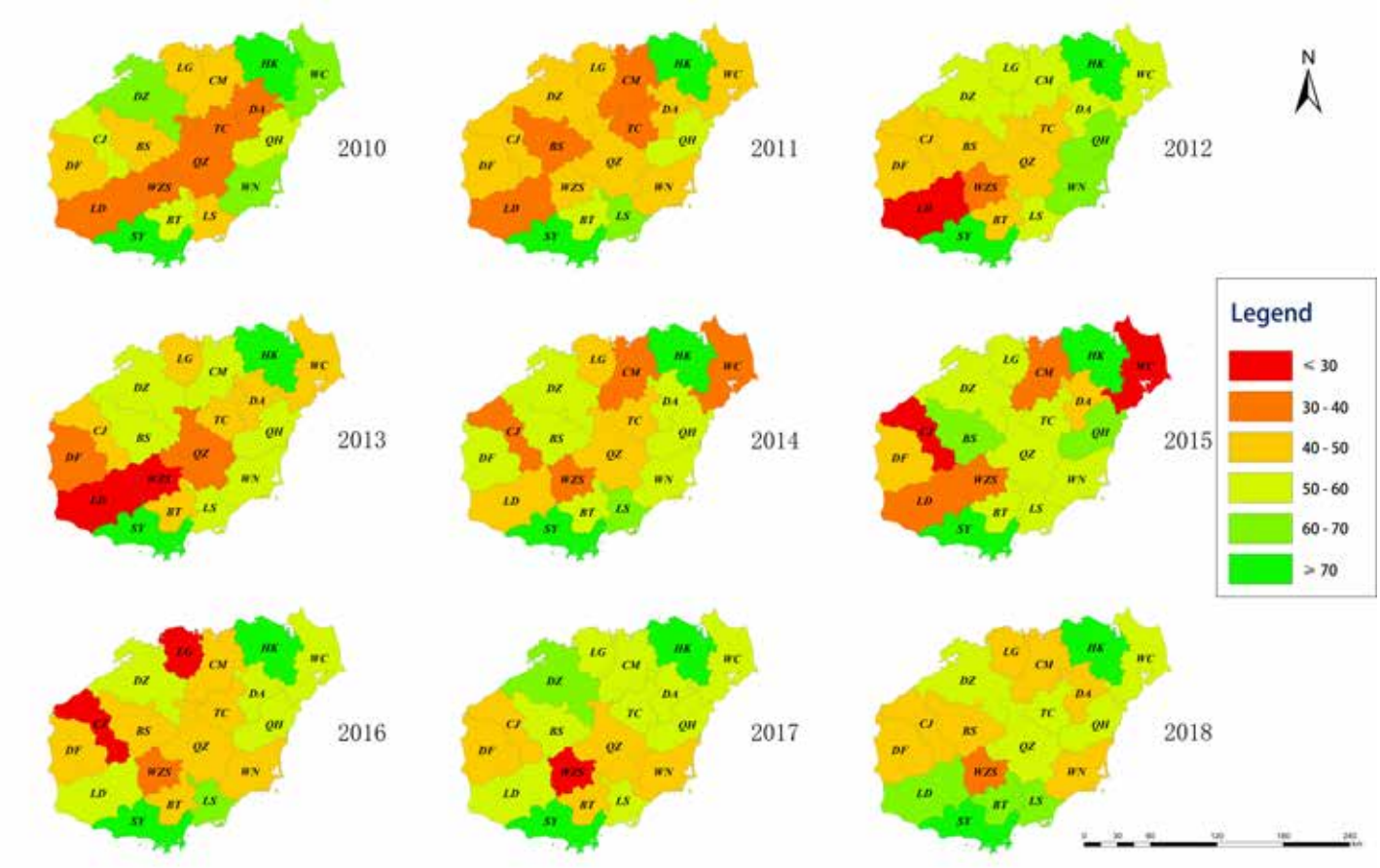
(a)



(b)

Figure 5. Comparison of population with (a) CO_2 emission and (b) GDP

Figure 6. Spatial distribution of sustainability in 18 cities and counties in Hainan Province. HK: Haikou City, SY: Sanya City, DZ: Danzhou City, WZS: Wuzhishan City, QH: Qionghai City, WCS: Wenchang City, WN: Wanning City, DF: Dongfang City, DA: Ding ‘an County, TC: Tunchang County, CM: Chengmai County, LG: Lingao County, BS: Baisha Li Autonomous County, CJ: Changjiang Li Autonomous County, LD: Ledong Li Autonomous County, LS: Lingshui Li Autonomous County, BT: Baoting Li and Miao Autonomous County, QZ: Qiongzhong Li and Miao Autonomous County.



4.2 Comprehensive analysis

Figure 6. Spatial distribution of sustainability in 18 cities and counties in Hainan Province. HK: Haikou City, SY: Sanya City, DZ: Danzhou City, WZS: Wuzhishan City, QH: Qionghai City, WCS: Wenchang City, WN: Wanning City, DF: Dongfang City, DA: Ding 'an County, TC: Tunchang County, CM: Chengmai County, LG: Lingao County, BS: Baisha Li Autonomous County, CJ: Changjiang Li Autonomous County, LD: Ledong Li Autonomous County, LS: Lingshui Li Autonomous County, BT: Baoting Li and Miao Autonomous County, QZ: Qiongzhong Li and Miao Autonomous County.

As shown in Figure 6, Hainan's development is unevenly distributed, mainly high in the north and south while low in the central and western regions. Haikou, the administrative center of Hainan Province, and Sanya, an important tourist city in China, have the highest level of sustainable development, with an annual comprehensive score of more than 70 points. Ledong County and Wuzhishan City in the southwest performed poorly in the sustainable development indicators. After 2015, influenced by Sanya City, the sustainable development level of Ledong County rose rapidly to third place in the province in 2018. In Danzhou City, Dongfang City, Chengmai County and Changjiang County, the main heavy industry bases in Hainan Province, the overall sustainable development index performance was poor, although the urban sustainable development index performed well in some years. The central inland region has a low urbanization rate, poor urban modernization, and the lowest level of sustainable urban development. By 2018, the city with the best sustainable development level in the province was Sanya City (81.34 points), followed by Haikou City (73.60 points). In the same year, Wuzhishan City only scored 31.93 points, while other cities scored between 45 and 60 points.

In general, as of 2018, the province with the best level of sustainable development is Sanya, followed by Haikou. In the same year, Wuzhishan has the lowest overall score, and the remaining cities have scores between 45 and 60.

5.Conclusion

Taking Hainan Province as an example, this paper constructs a sustainable development evaluation system at the city and county levels using an index based on SDGs. First, local data were combined with the specific indicators of SDG 11, SDG 13 and SDG 15 to obtain localized indicators. Secondly, the single indicator scores and development trends of 18 cities and counties in Hainan Province were obtained and compared to find out the advantages and disadvantages of each city and county in Hainan. Finally, a comprehensive score of cities and counties in Hainan Province was obtained through the score of single index, and the cities and counties with better sustainable development in the province and the cities and counties with insufficient sustainable development are identified for the sustainable development of cities and counties, providing a reference the sustainable development of cities and counties. The conclusions of this article are as follows:

(1) CO_2 emissions in all administrative regions of Hainan Province were relatively stable during 1997-2010, but increased sharply after 2010. After the Belt and Road Initiative was put forward in 2013, the increase of CO_2 emission in most regions slowed down again, except foranya and Haikou, which continued to grow. This index can provide a strong reflection of regional carbon emission status. Reducing carbon emission is one of the most direct and effective measures to achieve carbon neutrality.

(2) From 2010 to 2015, the overall sustainable development scores of all cities and counties

in Hainan Province fluctuated greatly. After 2015, with the promotion of the 13th Five-Year Plan of Hainan Province, the overall sustainable development level of Hainan Province has risen rapidly.

(3) From 2010 to 2018, the level of sustainable development in Hainan Province had a spatial distribution pattern showing that development was high in the north and south, but low in the central and western regions. Haikou as the administrative center and Sanya as the tourism center had the highest levels of sustainable development. The overall level of sustainable development of Wuzhishan needs to be strengthened.

This study uses 11 indicators related to SDG11 and SDG 13 were used to comprehensively evaluate the sustainable development status of cities in Hainan Province. However, more than one-third of the 230+ SDG indicators were related to SDG11. Future work should be combined with other SDGs related to cities, the Beautiful China Urban Evaluation Index, urban physical examination indicators, and the local Hainan Province government planning index. Using big data calculation and methods described in this paper to build a sustainable urban development indicator system in Hainan Province, and a comprehensive monitoring and evaluation process can be scaled out to other cities and counties for their sustainable development efforts.

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Pathway of achieving carbon neutrality: A city-level analysis in China's Xiong'an

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Abstract

Global climate change has attracted attention, especially since the adoption of the Paris Agreement in 2015. More than 100 countries and regions have proposed different forms of carbon neutrality goals, and have introduced science and technology development plans aiming at the technology needs of realizing carbon neutrality. As the key areas for carbon emissions, cities are the key to achieving "Carbon Neutrality" goal, but also the difficulty. The purpose of this paper is to provide a model city-level "Carbon Neutrality" analysis framework and construction path. Taking Xiong'an New Area as an example, this study identifies the range and boundary of carbon emission assessment in various sectors. Combining statistical yearbook data, nightlight data, and our Carbon Monitor technology (a near-real-time daily gridded fossil CO_2 emission dataset), this study then calculates the city's carbon emissions and further analyzes the status quo and characteristics of key emitting sectors. Also, this study effectively evaluates the carbon sink potential of Xiong'an New Area through calculation of forest carbon sink and cement carbon sink based on professional models and satellite remote sensing data. Combined with the expert opinions of key emission sectors, the paper provides guidance for the emission path and technology path of the Xiong'an New Area to achieve carbon neutrality, and further improve the supporting policy system of the demonstration project.

Keywords: Carbon Neutrality; City level; Carbon emission; Carbon sink; China

1.Introduction

Climate change is a major challenge to the survival and development of mankind in the 21st century. In December 2015, nearly 200 States Parties to the United Nations Framework Convention on Climate Change (UNFCCC) [1] unanimously adopted the landmark Paris Agreement at the Climate Change Conference in Paris, which established the overall framework for post-2020 global climate governance. In a carbon-neutral global context, countries have launched regionally specific mitigation strategies to achieve domestic net zero carbon emissions by 2050. The differences in such strategies are mainly due to different emission status and trends, and the different regional characteristics are mainly related to different land availability, population density and population trends.

At the same time, China has put forward an important strategic starting point for deepening various low-carbon pilot projects, namely “Net-Zero Carbon Emission Zone Demonstration Project”[2].

As the main source of carbon emissions, cities consume 78% of the world's energy with less than 2% of the world's land area, while producing more than 60% of total greenhouse gas emissions[3]. Therefore, the control of urban carbon emissions has become the main focus of demonstration projects in near-zero carbon emission zones. Since 2010, China has carried out pilot projects in low-carbon provinces and cities, and 87 provinces and cities have carried out pilot projects so far. However, the construction of carbon-neutral demonstration cities is not limited to the construction of low-carbon cities. Under the national "carbon neutral" vision, China is in urgent need of carrying out pilot projects of nearly zero carbon emissions based on the existing low-carbon pilot projects, and starting to support the realization of China's "carbon neutral" goal from the city level[3]. The Xiong’an New Area, a state-level new area decided by the CPC Central Committee and the State Council on April 1, 2017, has both policy advantages and late-mover advantages. Therefore, the construction of a "carbon neutral" pilot city in the Xiong’an New Area will provide practical experience and theoretical demonstration for China to achieve the goal of "carbon neutral", and provide path support for the development of China's ecological civilization and green region.

In this study, by drawing on the construction experience of near-zero carbon emission zones at home and abroad, combined with yearbook statistical data, night light data and our carbon monitoring technology, the carbon emission data of the Xiong’an New Area can be estimated, and the status quo and characteristics of major emission sectors in the Xiong’an New Area are further analyzed. In addition, based on professional models and satellite remote sensing data, the carbon sink potential of Xiong’an New Area is effectively assessed through the calculation of forest carbon sink and cement carbon sink. Finally, based on the data and results obtained above and the expert opinions from crucial areas, we guide for Xiong’an New Area to achieve a carbon-neutral emission path and technology path, and further improve the supporting policy system of demonstration projects.

2.sources of data on carbon emissions

Data sources in this study are mainly divided into three aspects: statistical yearbook, satellite remote sensing data and Carbon Monitor gridded dataset based on our previous work.

2.1 Statistical yearbook

When calculating the carbon emissions of the Xiong’an New Area in this study, considering that the Xiong’an New Area has not published comprehensive and reliable energy consumption data for calculating carbon emissions, this study first calculates the carbon emissions of the whole Hebei Province where the Xiong’an New Area is located. The energy consumption data used to calculate carbon dioxide emissions in Hebei Province can be collected from the energy consumption and

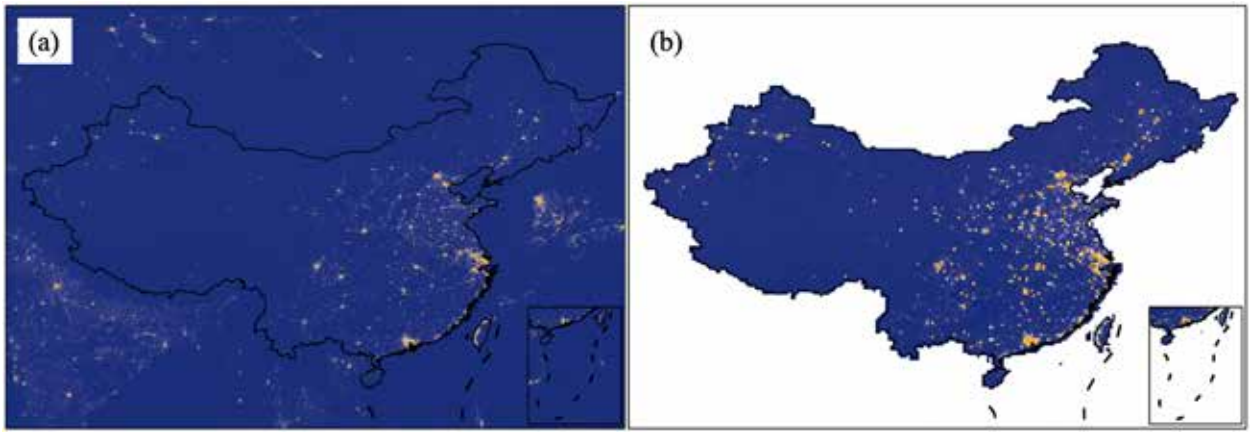


Fig.1. (a)The NPP-VIIRS nightlight DN value distribution in China in January 2018. (b)The resampled NPP-VIIRS nightlight DN value distribution in China in January 2018.

carbon emission data of each province from 2000 to 2018 in China Energy Statistical Yearbook. The carbon emission accounting in this study does not include the emissions of imported electricity and heat consumption from outside the borders of Hebei Province, and only focuses on fossil fuels consumed within the provincial borders.

2.2 Satellite remote sensing data

2.2.1 NPP-VIIRS nightlight data

The nighttime light data is 15 "x 15" grid data obtained from NOAA's Visible Infrared Imaging Radiometer Suite (VIIRS), one of the key instruments onboard the SUOMI National Polar Orbiter Partnership (SUOMI NPP) spacecraft. The onboard NPP-VIIRS sensor inherits the AVHRR (Advanced Very High-Resolution Radiometer) sensor from the National Oceanic and Atmospheric Administration and the MODIS (Moderate-Resolution) sensor from NASA Imaging Spectroradiometer and DMSP-OLS sensors with a total spectral range of 0.4-12.5 μm.

Day/night band (DNB), a band of NPP-VIIRS, is the main band used to detect the intensity of light at night. Compared with DMSP-OLS stable night light data, there is no so-called "oversaturation" of the data. Daily data can realize dynamic analysis of changes in short time intervals, but this data is greatly affected by cloud cover. In this study, we chose to use monthly NPP-VIIRS night light data from January 2013 to December 2018. Fig.1 (a) shows the distribution of NPP-VIIRS night light DN values in China in January 2018. Then, the original night-light data was resampled to the 0.25° grid using the area-weighted average method. The night-light data with a resolution of 0.25° resampled in January 2018 is shown in Fig.1 (b).

Night time light satellite remote sensing data can effectively detect urban nighttime light and even low-intensity nighttime light generated by small-scale residential areas and vehicle flows, which is a good data source for monitoring the intensity of human activities[4-6]. Since human activities are the main source of carbon emissions, and NPP-VIIRS night light image can effectively reflect the intensity of human activities, this study used noctilucent light data to estimate carbon emissions in Xiong'an New Area.

2.2.2 Land cover data

In this study, the carbon sink accounting for Xiong'an New Area mainly includes two aspects: forest carbon sink and cement carbon sink. Among them, there are many ways to

exert the function of forest carbon sink. Considering that it will not cause too much negative impact on the existing economic development model and development speed, the important way to increase the carbon sink in Xiong'an New Area is mainly through rational logging. While creating new woodland and forest growth space, Forest products (such as furniture, paper, etc.) are used to further sequester carbon. Therefore, the data used in the calculation of forest carbon sink are from China's land use data in 2018 provided by the Chinese Academy of Sciences and the data of average forest biomass density in Hebei Province[7]. As for another aspect of carbon sink accounting, cement not only emits large amounts of carbon during the production process, but also absorbs carbon dioxide from the outside world during the use process. The amount of carbon sink in this absorption process has not been paid attention to and quantified. This study quantifies the potential of cement carbon sink in Xiong'an New Area and calculates the cement carbon sink in Xiong'an New Area according to China's land use data in 2015 and China's cement carbon sink amount[8] in 2013 provided by the Chinese Academy of Sciences.

2.3 Carbon Monitor gridded dataset

The Carbon Monitor Gridded dataset (CM-G), a near-real-time gridded daily Fossil CO_2 Emission Dataset, elaborated at 0.1° × 0.1° resolution includes the six main 'super-sectors' of fossil CO_2 emissions: (1) Power, (2) Industry, (3) Residential consumption, (4) Ground transportation, (5) Domestic aviation, (6) International aviation, and (7) International shipping. For Industry sector, fossil fuel combustion and the cement production process are both considered. CM-G is derived from Carbon Monitor[9, 10], a near-real-time daily dataset of global CO_2 emission, including detailed information in 6 sectors and 13 main countries plus the rest of the world considered as an aggregate. Based on GID v1.0 and EDGARv5.0_FT2019 gridded spatial patterns of emissions and TROPOMI NO_2 retrievals, we constructed CM-G with a spatial resolution of 0.1° and a temporal resolution of one day. Compared with other gridded CO_2 emissions datasets,

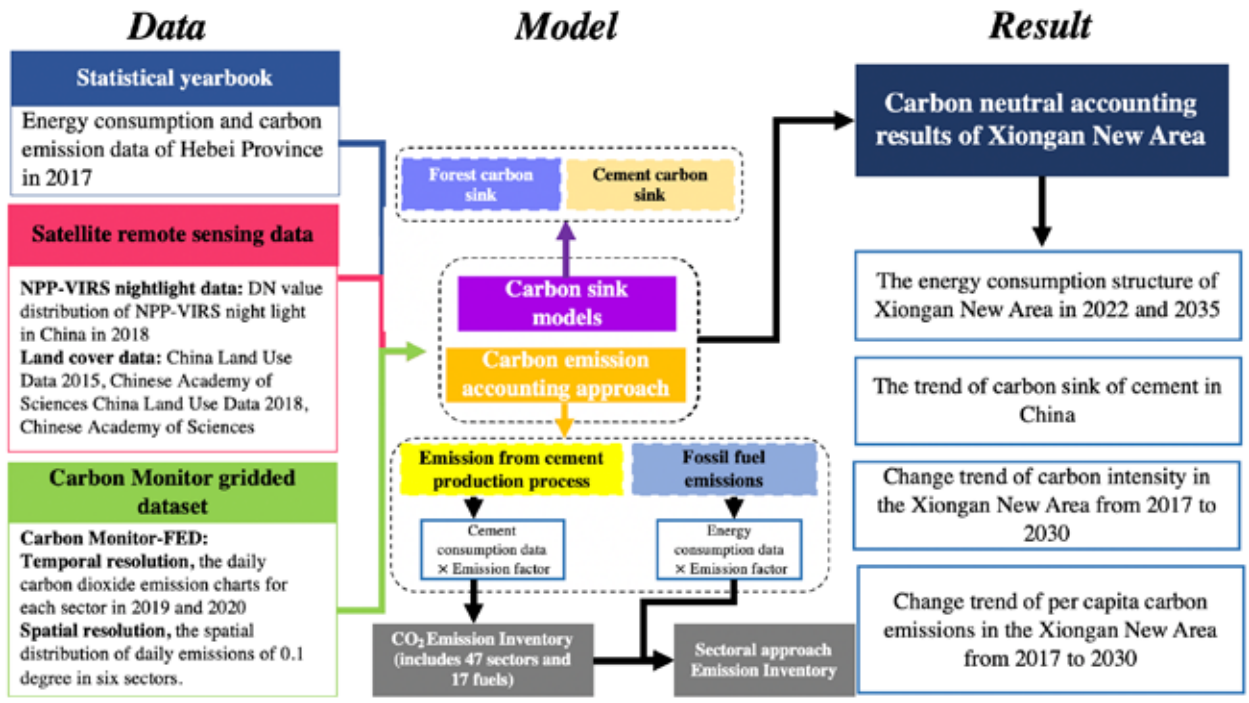


Fig.2. Carbon emission accounting framework.

CM-G has higher temporal and spatial resolution. From the perspective of temporal resolution, based on daily activity data, we estimated daily CO_2 emissions maps separately for every sector in 2019 and 2020. From the perspective of spatial resolution, we estimated the spatial distribution of daily emissions for six sectors with 0.1 degree.

3.Methods

3.1 Carbon emission accounting method

According to the greenhouse gas emission inventory guidelines provided by the Intergovernmental Panel on Climate Change (IPCC), [11, 12], this study adopts the sectoral accounting method to calculate the carbon emissions of each sector in a region, and the formula is as follows:

$$CE_{ij} = AD_{ij} \times EF_i \times M \quad (1)$$

Where, CE_{ij} CE_{ij}represents the carbon emissions generated by consuming fossil fuel *i* in sector *j*;AD_{ij} AD_{ij}represents the consumption of the corresponding fossil fuel type in the corresponding sector; EF_i EF_i represents the emission factor of fossil fuel *i*.

$$EF_i = NCV_i \times CC_i \times O_{ij} \quad (2)$$

NCV_i NCV_i represents the net calorific value, i.e., the calorific value generated per unit of fossil fuel *i*; CC_i CC_irepresents the carbon content, i.e., the carbon dioxide emission per unit of net calorific value generated by fossil fuel *i*; O_{ij} O_{ij} represents the oxidation rate, i.e., the oxidation rate of fossil fuel *i* in the combustion process of sector *j*.

3.2 Carbon sink models

At present, the ideas of emission reduction mainly include two aspects: one is to carry out technological transformation or technical recovery and treatment of carbon dioxide in many sectors, so as to achieve the purpose of energy saving and emission reduction. The second is to increase the carbon sink through various measures. The traditional carbon sink potential in Xiong'an New Area is to increase the forest carbon sink through afforestation and reforestation measures, and offset the industrial carbon dioxide emissions with the amount of carbon dioxide absorbed by the forest. In addition, cement is also an important carbon sink[13]. Cement exposed to the air will gradually absorb carbon dioxide in the air, resulting in carbonization reaction, which is a large net carbon sink in the world that has been neglected and has been increasing year by year.

There are several ways to exert the function of forest carbon sink. First, human beings accelerate the cultivation of forest resources and increase the accumulation and biomass of forest resources through afforestation and tending activities. Second, rational felling and utilization of forest resources; Third, forest products (especially wood) replace other raw materials, thus reducing carbon dioxide emissions in the production of other raw materials. In the calculation of forest carbon sink, this study calculated the total area of forest land in Xiong'an New Area of 700 hectares with the help of China's land use data in 2018 provided by the Chinese Academy of Sciences. According to The Mean Biomass Density Method (MBM), The forest carbon sink in Xiong'an New Area is estimated by the fol-

Fig.3. Composition of carbon emissions burning fossil fuel type in the industry sector (a), energy sector (b), residential consumption sector (c) and transportation sector (d).

lowing formula:

$$CS_f = A_f \times \overline{BD} \quad (3)$$

Where, $CS_f CS_f$ represents the forest carbon sink; $A_f A_f$ represents the forest area; $\overline{BD}\ \overline{BD}$ represents the average biomass density.

In the calculation of cement carbon sink, this study calculated that the built-up area of Xiong'an New Area was 276.48 square kilometers with the help of China's land use data in 2015 provided by the Chinese Academy of Sciences. The cement carbon sink of Xiong'an New Area is estimated according to the following formula:

$$CS_c = A_{total} \times CS_{ci} \quad (4)$$

Where, $CS_c\ CS_c$ represents the cement carbon sink; $A_{total} A_{total}$ represents the total area of built-up area; $CS_{ci}\ CS_{ci}$ represents the cement carbon sink in every built-up area *i*.

Table.1. Carbon emissions of 47 sectors in the Xiong'an New Area in 2017

	Energy-related emissions (kilotons)	Emission from cement production process (10 kilotons)	The total emissions (10 kilotons)
Total consumption	801.13	29.82	830.94
Water conservancy in agriculture, forestry, animal husbandry and fishery	7.94	-	7.94
Coal selecting	40.02	-	40.02
Oil and gas drilling	1.47	-	1.47
Ferrous metal mining	1.76	-	1.76
Nonferrous metal mining	0.07	-	0.07
Nonmetallic ore mining and dressing	0.15	-	0.15
Other mineral extraction and selection	0.00	-	0.00
The harvesting and transportation of timber and bamboo	0.00	-	0.00
Food processing	1.84	-	1.84
Food production	0.48	-	0.48
Beverage production	0.34	-	0.34
Tobacco processing	0.05	-	0.05
Textile industry	0.70	-	0.70
Clothing and other fiber products	0.10	-	0.10
Leather, fur, down and related products	0.23	-	0.23
Wood processing, bamboo, sugar cane, palm fiber and straw products	0.21	-	0.21
Furniture manufacturing	0.08	-	0.08
Paper and paper products	1.22	-	1.22
Printing and recording media reproduction	0.05	-	0.05
Culture, education and sports articles	0.02	-	0.02
Petroleum processing and coking	6.28	-	6.28
Chemical raw materials and chemical products	6.51	-	6.51
Pharmaceutical products	0.09	-	0.09

	Energy-related emissions (kilotons)	Emission from cement production process (10 kilotons)	The total emissions (10 kilotons)
Chemical fiber	0.05	-	0.05
Rubber products	0.10	-	0.10
Plastic products	0.16	-	0.16
Nonmetallic mineral products	10.43	29.82	40.25
Ferrous metal smelting and pressing	376.40	-	376.40
Nonferrous metal smelting and pressing	0.54	-	0.54
Metal products	0.85	-	0.85
General machinery	3.09	-	3.09
Special equipment	0.60	-	0.60
Transportation equipment	0.78	-	0.78
Electrical equipment and machinery	0.31	-	0.31
Electronic and telecommunication equipment	0.22	-	0.22
Instrumentation culture office machinery	0.05	-	0.05
Other Manufacturing Industries	0.05	-	0.05
Scrap and Waste	0.06	-	0.06
Production and supply of electricity, steam and hot water	256.50	-	256.50
Natural gas production and supply	0.05	-	0.05
Tap water production and supply	0.02	-	0.02
building	2.45	-	2.45
Transportation, warehousing, post and telecommunications services	19.73	-	19.73
Wholesale, retail trade and catering services	8.31	-	8.31
other	5.06	-	5.06
city	16.49	-	16.49
rural	29.24	-	29.24

4.Results

4.1 The definition of the range and boundary of carbon emission assessment in different sectors

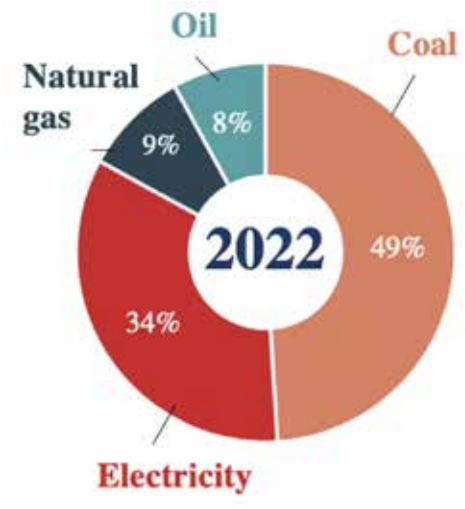
Referring to the Guidelines for Preparing Provincial Greenhouse Gas Inventory issued by the National Development and Reform Commission, and combining with the energy balance sheet and nighttime light data of Hebei Province, this study calculates the carbon emissions in the four sectors of industry, energy, residential consumption and transportation (Fig.3). According to calculation, the total emissions from the industry sector are 4.96 million tons, including 4.66 million tons of energy-related emissions and 300,000 tons of industrial process emissions. Total emissions in the energy sector were calculated to be 2.57 million tons; The total emission in the residential consumption sector is 460,000 tons; Total emissions from the transportation sector are estimated to be 200,000 tons.

4.2 Carbon emission accounting results of Xiong'an New Area

In 2017, the total emission of Xiong'an New Area from the perspective of consumption was 8.31 million tons, of which the specific carbon emission of 47 sectors is shown in Table 1 below:

According to the development plan, the total energy consumption in the Xiong'an New

(a)



(b)

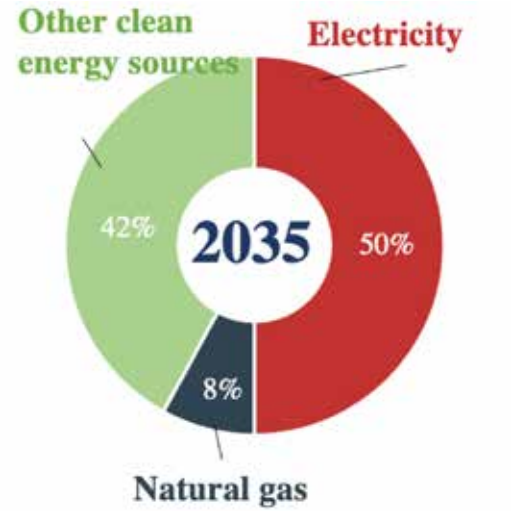


Fig.4. Energy consumption structure of Xiong'an New Area in 2022 (a) and 2035 (b)

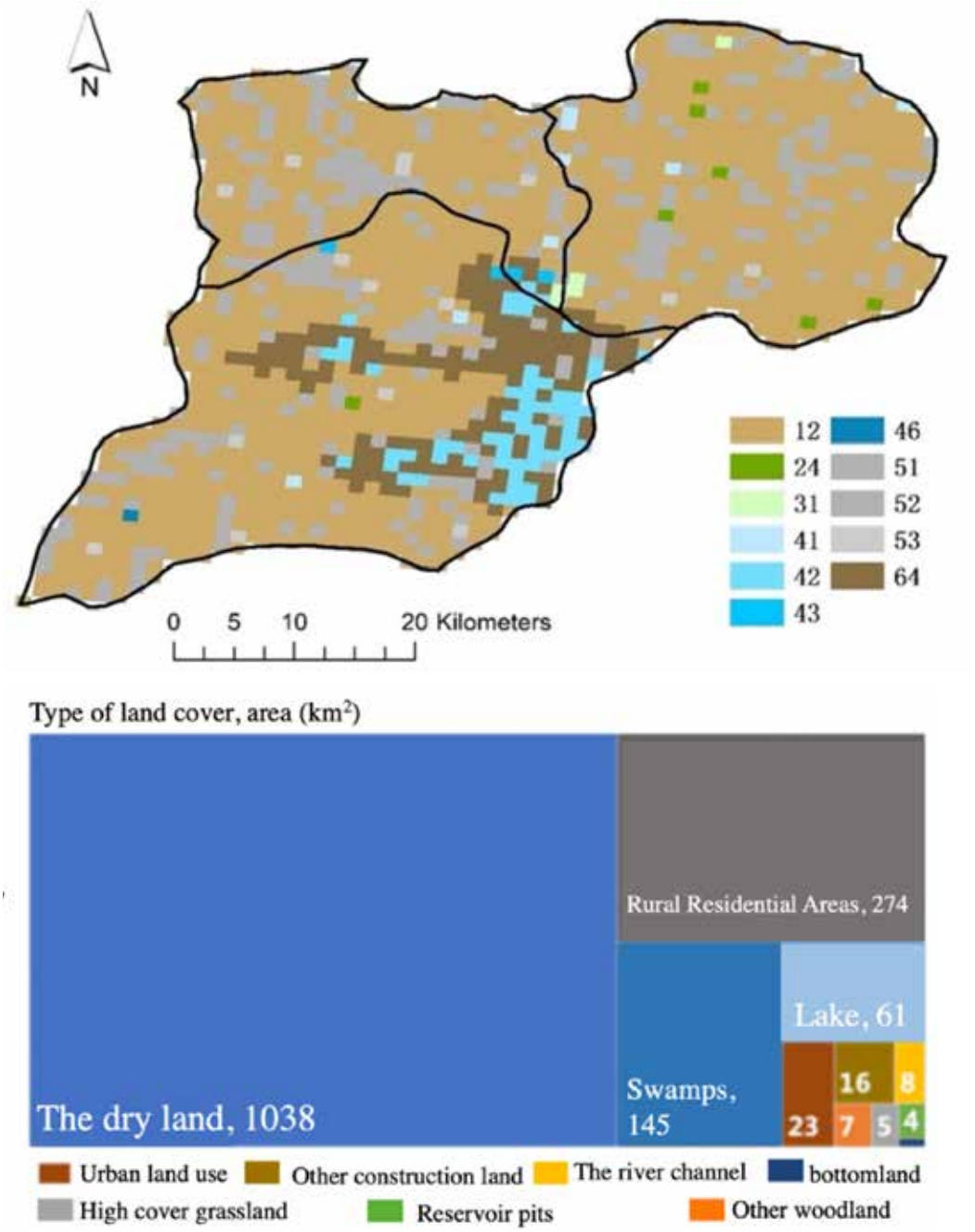


Fig.5. Statistics of land use and land cover area of various types in Xiong'an New Area. (See SI for the corresponding names and meanings of the land cover data numbers)

Area in 2022 will be 3.8 million tons of standard coal, of which natural gas consumption accounts for 9 percent, coal consumption accounts for 50 percent, petroleum (refined oil) consumption accounts for 8 percent and electric energy consumption accounts for 34 percent of terminal energy consumption (Fig.4). According to the IPCC guidelines, the study estimates that the total emissions from the Xiong'an New Area will be reduced to 6.07

million tons by 2022, based on the formulas (1) and (2) mentioned above. According to the development plan, in 2035, the total energy consumption in the Xiong'an New Area will be 8.6 million tons of standard coal, of which the proportion of natural gas consumption will be less than 8%, without coal consumption, the proportion of petroleum (refined oil) consumption will drop to 0.2%, and the proportion of electric energy consumption in the terminal energy consumption will be more than 50%. In addition, geothermal energy, photovoltaic energy, biomass and other renewable energy utilization scale in the area is further expanded, and together with the green power and hydrogen energy transferred from outside the area, Xiong'an Green Energy supply system is formed. According to the calculation of this study, Xiong'an New Area will only produce 1.07 million tons of carbon emissions by 2035.

4.3 Carbon sink accounting results of Xiong'an New Area

The forest carbon sink of Xiong'an New Area was calculated according to the above formula. Combined with relevant studies, the average forest biomass density in Hebei Province was 23.7 tons/ha (Jingyun Fang et al., 1996). Therefore, the forest carbon sink of Xiong'an New Area in 2018 was estimated to be 16,590 tons of carbon, about 60,000 tons of carbon dioxide.

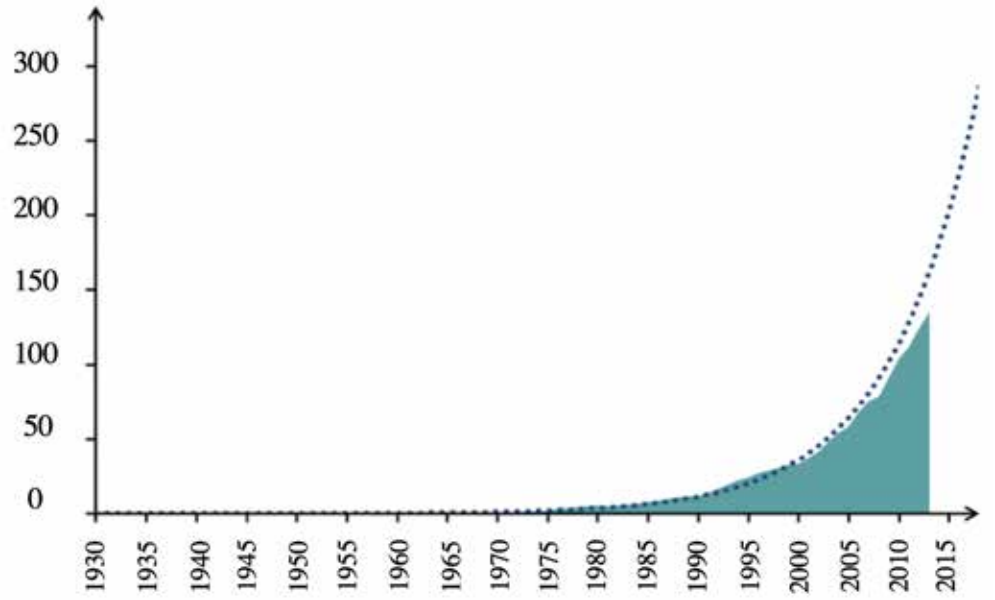


Fig.6. Change trend chart of China's cement carbon sink.

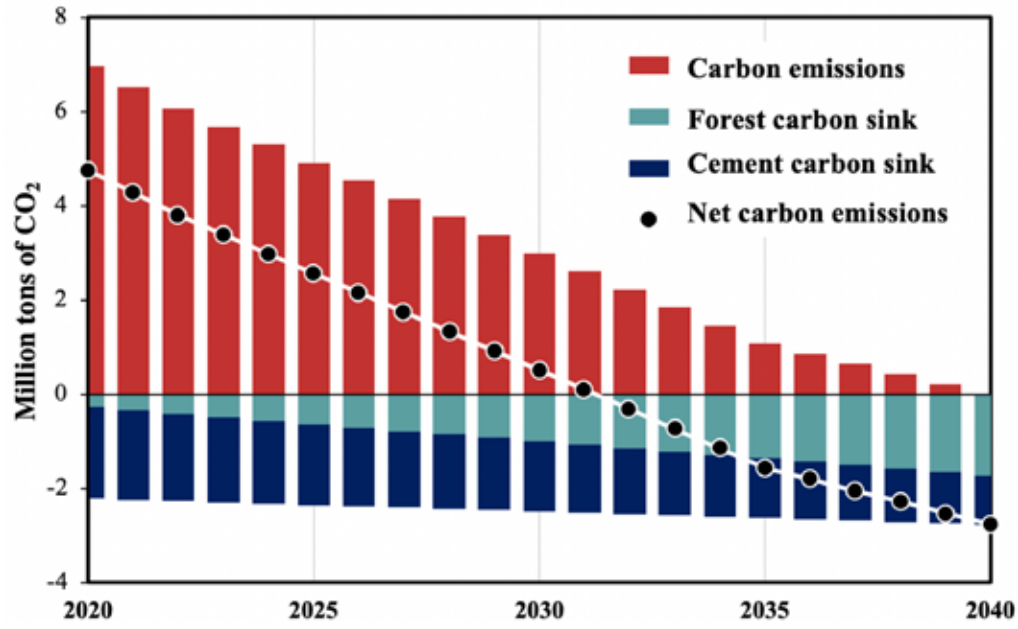


Fig.7. Expected carbon neutrality of Xiong'an New Area in the future.

Meanwhile, Xiong'an New Area is committed to achieving the overall goal of 70% of the blue and green space and 40% of the forest coverage rate in the new area through large-scale afforestation and urban greening. The green coverage rate in the starting area is 50%, and that in the village group is 45%. The total area of scientific and technological forest in the urban construction group is 230,000 mu. Overall, it will absorb up to 1.36 million tons of carbon dioxide.

In the calculation of cement carbon sink in Xiong'an New Area, combined with relevant studies [8], China's cement carbon sink was 135 million tons in 2013, which showed an exponential growth trend during 1930-2013. The trend line of China's cement carbon sink index function (Fig.6) fitted accordingly estimated that China's cement carbon sink was about 205 million tons in 2015.

At the same time, with the promotion of infrastructure construction in the New Area, the total construction area of the New Area will reach 240 million square meters in 2030[14], and all new buildings will meet the latest energy-saving building standards. It is estimated that the cement carbon sink of the New Area in 2030 will reach 1.27 million tons of carbon dioxide.

4.4 Carbon neutral accounting results of Xiong'an New Area

The results of this study show (Fig.7) that according to the overall planning goals of the Xiong'an New Area, the Xiong'an New Area can fully rely on renewable energy and achieve the goal of "zero carbon emission" as early as 2040. Under this scenario, carbon emissions would decline rapidly, falling to about 3 million tons in 2030, to about 1 million tons in 2035, and to zero in 2040. In contrast, the sink of forests and green buildings will rise steadily. In terms of net carbon emissions, the Xiong'an New Area will reach nearly zero emissions by 2030 and become fully carbon neutral by around 2031. By 2035, 1.56 million tons of negative carbon emissions will be achieved.

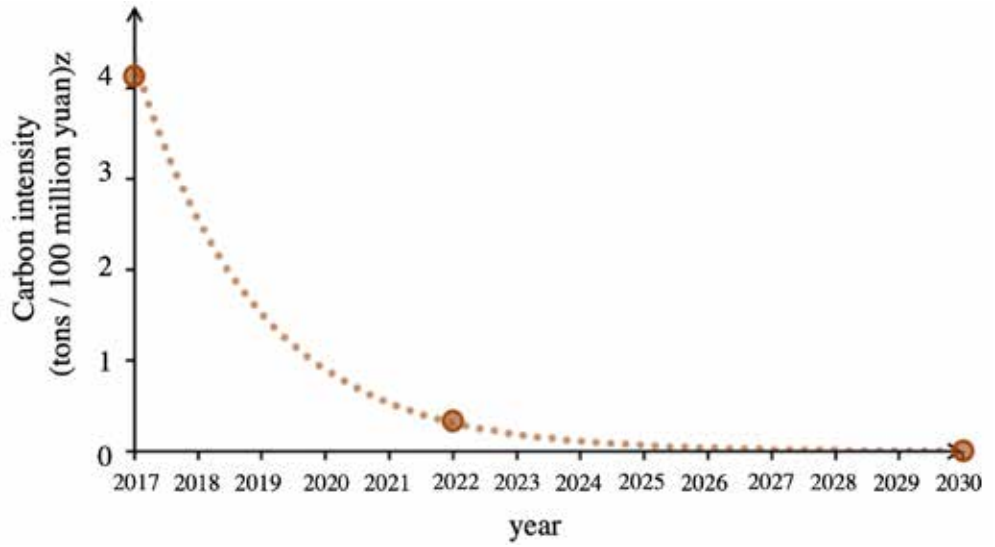


Fig.8. Change trend of carbon intensity in the Xiong'an New Area from 2017 to 2030.

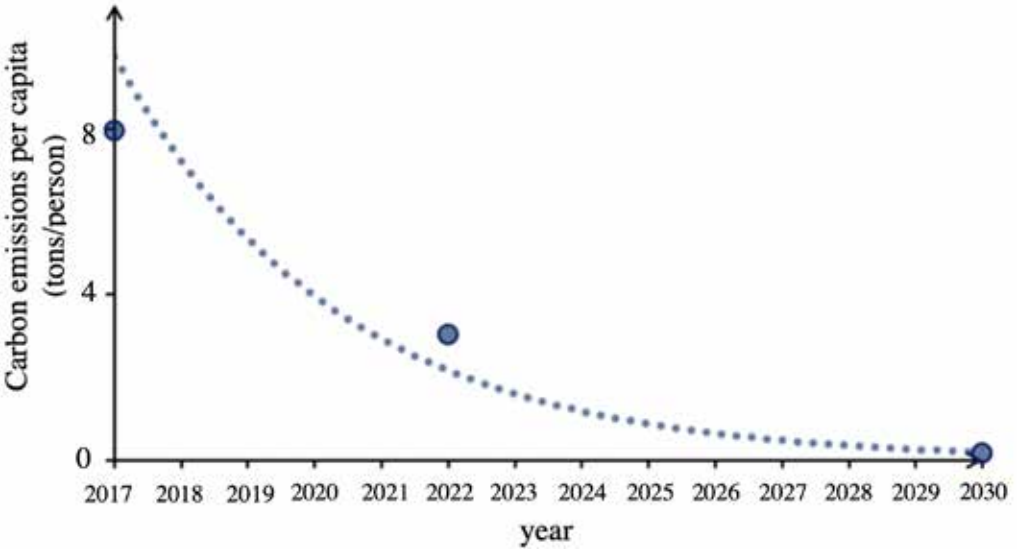


Fig.9. Change trend of per capita carbon emissions in Xiong'an New Area from 2017 to 2030.

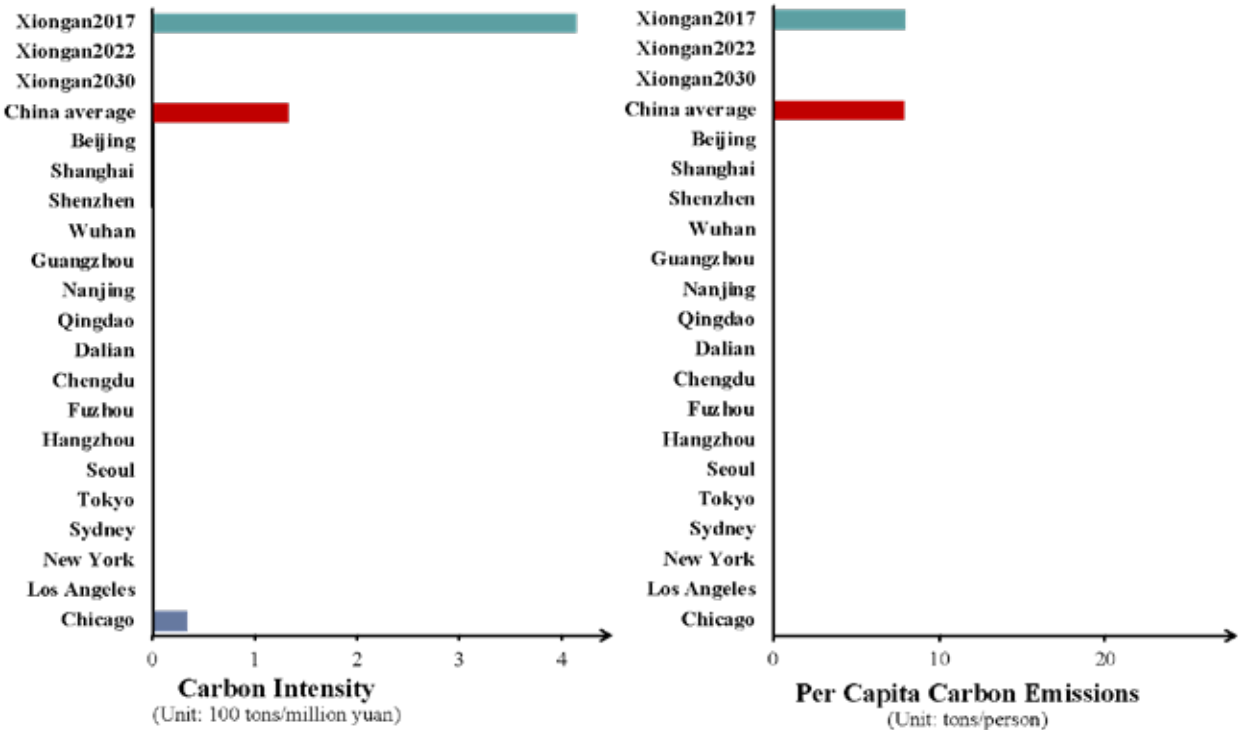


Fig.10. Comparison of carbon intensity(a) and per capita carbon emission(b) between Xiong'an New Area (2017, 2022, 2035) and other typical cities at home and abroad (2017).

However, from the perspective of carbon intensity (carbon emissions per unit of GDP) (Fig.8) and per capita carbon emissions(Fig.9), the Xiong'an New Area's carbon intensity and per capita carbon emissions showed a sharp exponential decline from 2017 to 2030.

Compared with typical C40 cities at home and abroad, Xiong'an New Area has a greater potential for carbon neutral (Fig.10). The C40 Cities Group is an international coalition of cities working to combat climate change. Including China, the United States, Canada, the United Kingdom, France, Germany, Japan, South Korea, Australia and other countries city members. Before the construction of the Xiong'an New Area started in 2018, the carbon intensity of the Xiong'an New Area in 2017 was relatively high due to the underdeveloped economic development level, and the per capita carbon emission was relatively high due to the relatively small population.

With the orderly development of the new area, the per capita carbon emissions of the Xiong'an New Area will be much lower than those of foreign C40 cities such as Sydney with a similar population size, and the carbon intensity will also be significantly lower than that of domestic C40 cities such as Qingdao, Nanjing and Hangzhou with a similar economic scale. Compared with foreign C40 cities, Xiong'an's economic and population size in 2030 will be similar to that of Sydney, but its carbon emission level is much lower than that of Sydney, showing significantly lower carbon intensity and per capita carbon emission level. Compared with domestic C40 cities, Xiong'an's economic scale in 2030 will be equal to that of Qingdao, Nanjing, Wuhan,

Chengdu and other C40 cities, but its carbon emission level is much lower than those of these cities, showing a lower carbon intensity.

5.Summary and discussion

5.1 Development path of carbon neutral technology in Xiong'an New Area

At the present stage, the mainstream ideas of emission reduction in the world are mainly divided into two aspects: one is to carry out technological transformation or technological recovery and treatment of carbon dioxide in residential consumption, transportation, industry, energy and other sectors, so as to achieve the purpose of energy saving and emission reduction. The second is to increase the carbon sink through various measures. The traditional carbon sink potential in Xiong'an New Area is to increase the forest carbon sink through afforestation and reforestation measures, and offset the industrial carbon dioxide emissions with the amount of carbon dioxide absorbed by the forest.

Of this study is based on the first kind of emissions reduction ideas, combining carbon emissions and carbon sequestration calculation results, according to the Xiong'an new area emission reduction technology system and expert investigation, more specific technical measures for residential consumption near zero carbon for reference are given from the 98 technical measures(Table.2-5), these measures are mainly divided into two categories: one kind is applicability of the technique, the expert investigation scored five points of technical measures; The second is the applicability of strong technology, that is, the technology is divided into 3-4 points(Fig.11).

Table.2. Technical measures suitable for residential consumption sector

Classification of technical measures	Name of technical measure	Applicability
Overall planning	Low-carbon community planning	High suitability
Property management	Intelligent property management system	Suitability
	Community carbon emission management system	Suitability
Building renovation	Solar water heating system	High suitability
	External shading renovation	High suitability
	Outside the window transformation	High suitability
	Elevator Energy Recovery	High suitability
	Elevator group control measures	High suitability
	Roof greening	High suitability
	Vertical greening	High suitability
Replacement of power structure	Energy saving transformer	High suitability
	Distributed photovoltaic power generation	High suitability
Lighting technology	Electrodeless fluorescent lighting based on inductive coupling	High suitability
	Promote LED energy-saving lamps	High suitability
	High efficiency intelligent power saving controller for lighting	High suitability
Other measures	Popularization of energy-saving behavior	High suitability
	Special-purpose energy conservation training	High suitability
	Energy consumption monitoring statistics database	High suitability
	Demonstration Base Construction	High suitability
	Garbage sorting and recycling	High suitability
	Resource utilization of solid waste	High suitability
	Unconventional water use	High suitability
	Vegetation increases carbon sinks	High suitability
	Regional carbon emission monitoring system and personal carbon account	High suitability
	Household low-carbon consumption	Suitability
	Green travel for residents	Suitability
	Community carbon HP system	High suitability

Table.3. Technical measures suitable for transportation sector.

Classification of technical measures	Name of technical measure	Applicability
Infrastructure construction	Bus Rapid Transit Development	High suitability
	Regular Bus Development	High suitability
	Time-sharing rental of electric vehicles	High suitability
	Rail Transit Development	High suitability
Road Traffic Facilities	The electric car	High suitability
	Fuel cell vehicle	Suitability
	Natural gas vehicle	Suitability
	Solar car	Suitability
	Engine energy saving technology	High suitability
	Intelligent Traffic Management	High suitability
Railway technical facilities	Energy-saving lighting systems have been upgraded	Suitability
	Station retrofitted with LED lamps	Suitability
	Other railway management energy conservation projects	Suitability
	Regenerative Braking Energy Saving	High suitability
Traffic Policy Measures	Encourage green travel and voluntary driving	High suitability
	Guide the transformation of travel mode to rail travel	Suitability
	Reinvent the slow system	High suitability

Table.4. Technical measures suitable for industry sector

Classification of technical measures	Name of technical measure	Applicability
Power distribution system efficiency improvement technology	Energy-saving technology of dynamic harmonic suppression and reactive compensation	High suitability
Comprehensive management of enterprise energy use to improve technology	Process energy consumption control technology system technology	High suitability
	High energy consumption equipment timing on, off and other related measures	High suitability
	High efficiency electromagnetic induction heating technology	Suitability
Combustion efficiency improvement technology	Energy-saving technology of heat storage combustion without induced draft fan and directional valve	Suitability
	Focused energy combustion technology	Suitability
Power saving technology for facilities	High voltage frequency conversion speed regulation technology	High suitability
	Frequency conversion speed regulation energy saving technology	High suitability
	Intelligent lighting control technology	Suitability
Renewable energy technologies	Distributed photovoltaic power generation	High suitability
	Distributed geothermal power generation	High suitability
	Waste power generation technology	High suitability
Breakthrough carbon reduction technology	New melting reduction process for iron and steel	Suitability
	Iron and steel electrolytic iron ore process	Suitability
	Clinker substitution in cement industry	High suitability
	Carbon dioxide storage technology	Suitability
Clean energy technologies	Coal to gas technology	High suitability
	Oil to gas technology	High suitability
Improve the utilization technology of recycled raw materials	Increase the ratio of scrap iron in steel raw materials	Suitability
	Increase the proportion of recycled aluminum in aluminum processing	High suitability

Table.5. Technical measures suitable for energy sector.

Classification of technical measures	Name of technical measure	Applicability
Coal-fired power plant technology	Natural gas ignition replaces kerosene ignition	High suitability
	Technical renovation of steam boiler air preheater	High suitability
	High efficiency motor replacement	High suitability
Gas power plant technology	Heating surface is added at the end of the waste heat boiler	Suitability
	Realization of pure condensate turbine unit to realize combined heat and power generation technology	Suitability
	Gas turbine rotor cooling air waste heat utilization	Suitability
	Gas turbine intake cooling	Suitability
Power structure substitution	New gas-fired power generation	High suitability
	Distributed photovoltaic power generation	High suitability
	Distributed geothermal power generation	High suitability
	Increase the utilization hours of existing gas-fired power generation	Suitability
	Garbage power generation	High suitability
	Triple generation technology of cold, heat and power	High suitability
	Outsourcing green power	High suitability

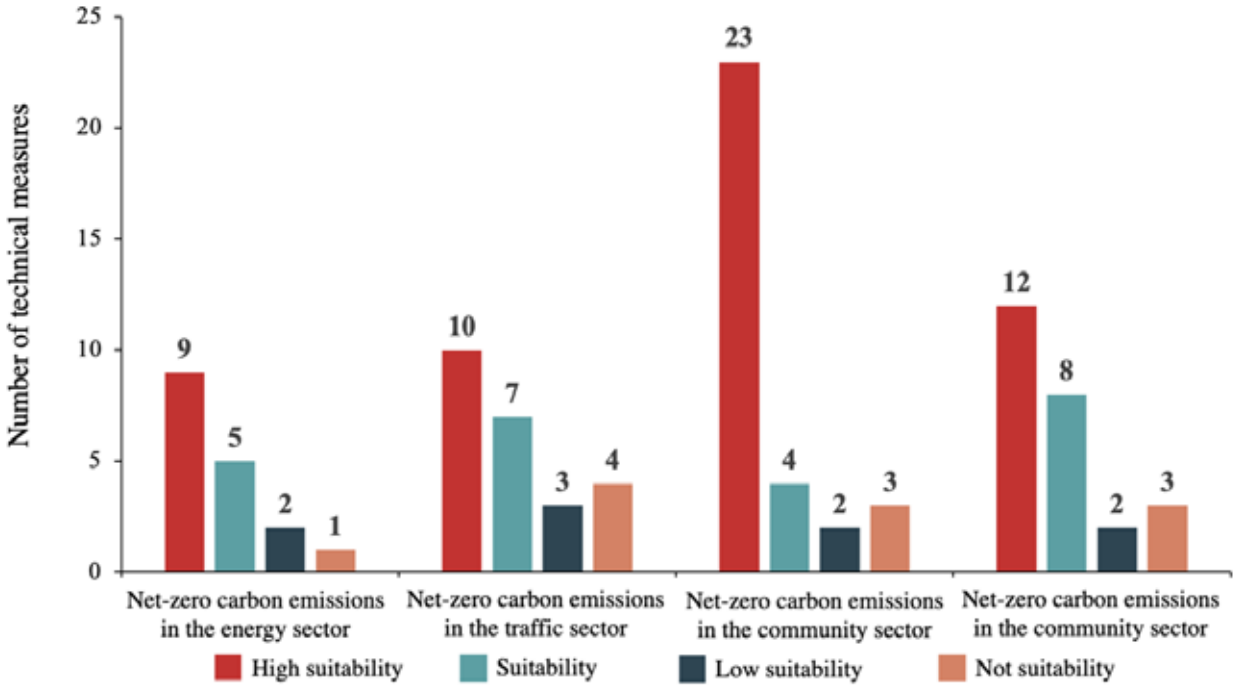


Fig.11. The applicability distribution of the 98 technical measures in various sectors.

5.2 Suggestions on supporting policy system for carbon neutral in Xiong'an New Area

On the basis of top-level policy design, the government should actively promote the construction of demonstration projects in near-zero carbon emission areas and apply the policy design to specific green development projects, so as to combine green development with economic development and realize low-carbon development industry and technological innovation. At the same time, a transparent and open government management system and government service information platform should be built to enhance public participation and make the government's planning and design public in real time.

In the residential consumption sector, carbon emission monitoring system for residential areas and reasonable compact urban layout can be adopted, and green carbon absorbing building materials and low-carbon construction technologies can be promoted. At the same time, we will strengthen financial subsidies and support to attract and encourage people to participate in the policy management of renewable energy use, so as to form a sustainable residential ecosystem.

In the field of transportation, policies and management such as integrating land use and transportation planning, reducing traffic congestion, improving the efficiency of the transportation system, improving vehicle technology and fuel performance, and reducing greenhouse gas emissions of motor vehicles should be adopted to transform the energy-consuming urban transportation mode into an environmentally friendly urban transportation mode.

In the industry sector, strengthen regulatory measures (e.g., management of greenhouse gas emission inventories, etc.) through fiscal means and financing mechanisms; Implementing energy efficiency or energy intensity standards; Implement equipment standards and other technical specifications, etc.) and other policies and management, accelerate energy conservation construction projects, and promote energy saving products at the same time, forcing industrial transformation from the consumption end to the production end.

In the field of energy, the direction from the promotion of new energy integrated services related business, to meet the production and consumption of the end user, on sales of new energy, new energy planning and design, project investment and construction, so as to realize the energy field near zero carbon emissions, and build new energy subsidies or reward mechanism, increase the market share of new energy.

In addition, we should further strengthen publicity and guidance, promote the awareness of local governments and relevant subjects, combine the construction of demonstration projects with local economic and social development, and drive the formation of green and low-carbon new growth points and new drivers through the projects, so as to achieve a win-win situation between carbon emission control and economic development.

At present, professionals in the industry have a positive attitude towards the results of the carbon neutral demonstration project in

Xiong'an New Area. This study will provide practical experience and theoretical demonstration for China to achieve the goal of "carbon neutrality", which is considered to be very beneficial to the development of China's ecological civilization and green region. However, there are still some limitations in this study, such as whether the carbon-neutral path in Xiong'an New Area is applicable to most cities, and a large number of case studies are needed to confirm these conclusions.

6.Acknowledgments

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Supplemental Information

Table.S1. The corresponding names and meanings of the land cover data numbers.

Number	Term	Definition
12	The dry land	Cultivated land without irrigation sources or facilities, where crops are grown by natural water; Arable land for dry crops with water and irrigation facilities that can be irrigated normally in normal times of year; Arable land mainly for growing vegetables.
24	Other woodland	Refers to unformed woodlands, nurseries and gardens (orchards, mulberry gardens, tea gardens, tropical crop gardens)
31	High cover grassland	Means covering more than 50% of natural grassland, improving grassland and mowing grassland. This kind of grass generally better moisture conditions, grass growth dense.
41	Natural gas vehicle	Refers to naturally formed or artificially excavated rivers and land below the annual water level. Artificial canals include embankments.
42	The river channel	A naturally formed area of stagnant water, and land below the annual water level.
43	Reservoir pits	A man-made water storage area, and land below the annual water level.
46	Bottomland	Land between the water level of a river or lake during normal and flood periods.
51	Urban land use	Refers to large, medium and small cities and counties and towns above the built-up area land.
52	Rural Residential Areas	Rural settlements that are independent out of towns and cities.
53	Other construction land	Refers to land for factories and mines, large industrial areas, oil fields, salt works and quarries, as well as roads, airports and special land.
64	Swamps	Refers to the land which flat low-lying terrain, poor drainage, long-term wet, seasonal or perennial water, and the surface growth of wet plants.

Fighting plastic pollution with artificial intelligence and citizen science

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1.Introduction

1.1 Plastic pollution and its adverse impact

Plastic is a versatile material that can respond to countless needs of the industry and consumers. Because of this high utility, the production of plastic has outpaced any other synthetic material since 1950 was estimated reaching 8.3 billion metric tonnes in 2017 already. Even the temporary economic slowdown due to the COVID-19 pandemic is unlikely to dampen the strong growth in this sector. In 2019, global plastics production almost reached 370 million tonnes per year. At the same time, only less than 15 percent of the plastic produced globally is actually recycled. This means, without action, the annual flow of plastic into the ocean will nearly triple by 2040, to 29 million metric tons per year (range: 23 million-37 million metric tons per year).

Asia has driven the growth in plastic production over recent decades, at 51% of the global production (31% China, 3% Japan, 17% Rest of Asia) and is also the leading plastic consumer. Per capita plastic use in the region is growing at a faster rate than in other regions. Eleven of the top 20 polymer producers are based in Asia including five in China. At the same time, waste management capacity, including infrastructure and policy development and enforcement capability, is highly challenged especially since the region experienced a major surge in simple-use plastic product use and disposal in form of personal protection and hygiene gears (e.g. masks) and packaging in online shipping due to the pandemic. Additionally, this region is believed to host numerous hotspots of plastic leakage into the natural environment, making the negative impacts of plastic produced, used or disposed here higher.

In recent years, global attention to marine litter and plastic pollution has surged. All but one in the top 10 pollution countries and 43 of the top 50 polluting rivers are in Asia. The majority of marine litter is plastic, which is discarded as “waste” without recycling or incineration.

Globally The United Nations Environment Assembly, at its first, second, third and fourth sessions, in 2014, 2016, 2017 and 2019 respectively, adopted resolutions 1/6, 2/11, 3/7, 4/6 and 4/9 to address the environmental impacts of marine plastic litter and pollution from single-use plastic products. The European Union issued a new directive, 2019/904, on the reduction of the impact of certain plastic products on the environment. From 3 July

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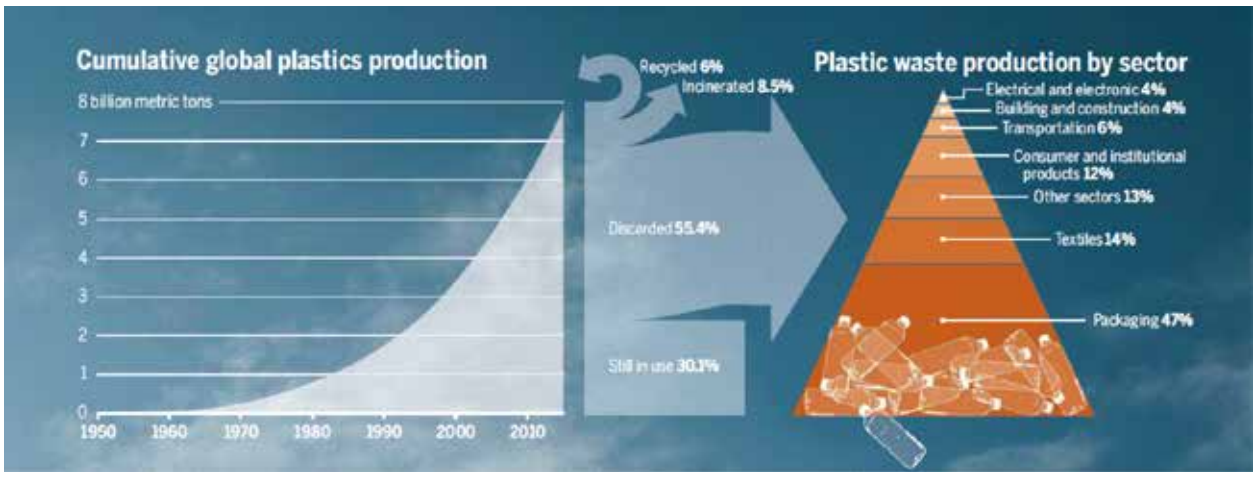

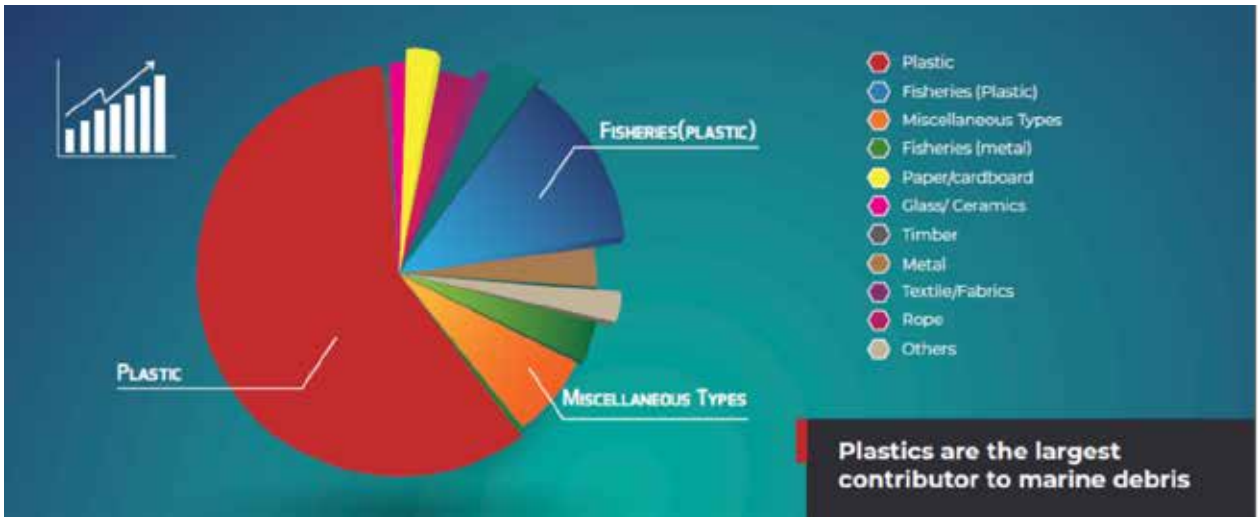

2021, the EU Member States cannot sell or distribute single-use plastic plates, cutlery, straws, balloon sticks and cotton buds as well as cups, food and beverage containers made of expanded polystyrene and any product made of oxo-degradable plastic. Countries have formulated national policies to combat plastic pollution also. For example, on 15 February 2021, the Cabinet of the Government of Thailand approved a plan to phase out and ban four types of plastic products, i.e. Lightweight plastic bags of less than 36 micron thickness, Styrofoam food containers of less than 100 micron thickness, Single-use plastic cups of less than 100 micron thickness, and plastic straws, by 2022. The country is to increase recycling of seven more plastic products also.

In India, the Prime Minister Modi, on the occasion of the World Environment Day celebration on the 5th June 2018, made a public pledge to phase out single use plastic by 2022. In keeping with the pledge, the Ministry of Environment, Forest and Climate Change, Government of India, notified the Plastic Waste Management Amendment Rules, in August 2021, prohibiting with effect from the 1st July 2022, the manufacture, import, stocking, distribution, sale and use of polystyrene and expanded polystyrene and a range of plastic

commodities, such as ear buds with plastic sticks, plastic sticks for balloons, plastic flags, plastic plates, cups, stirrers and cutlery, and wrapping or packing films around sweet boxes, invitation cards, and cigarette packets.

While these plastic reduction policies will be effective in curbing uncontrolled use of the plastic, gaps in scientific knowledge on where and how the plastic is leaking into the environment still not fully understood. Effectiveness of different measures to reduce the plastic pollution is another area of limited comprehension. Without more baseline information on the existing plastic pollution and the data and scientific insight about how the plastics becomes the pollution in waterways, rivers, wetlands, and then in the coastlines and ocean, and even in the atmosphere, there will always be a risk of policies being ad-hoc with limited positive and sustainable outcomes and with risk of losing the support of local administrators and the general public.

Throughout 2020 and 2021, the covid-19 pandemic shifted the practices of plastic product manufacturing, use, disposal, and even recycling. The UNEP's work effort to fight the plastic pollution in rivers in Asia has faced some severe setbacks and additional challenges in 2020 to 2021 due to. COVID-19 brought changes in plastic use, lifestyles and consumer behavior due to measures to prevent the spread of infection including mobility restrictions. The COVID-19 pandemic. The pandemic has:

1. Increased the consumption and disposal of Single-use plastic products (SUPP). As much as 40% increase in the volume of medical waste generated globally (IFC 2020). In West Java, Indonesia, the healthcare waste generation jumped by 30% between January and April 2020.Some 53% increase in plastics in household waste were in a study conducted in 23 countries (Filho, 2021).
2. Changed sentiment over plastic, wherein 'convenience' in plastics consumption has been accompanied by the strengthened 'safety & hygiene' concerns fueled by consumer anxiety driving the increased use of disposable plastics, and unacceptance to re-usable;
3. Altered the landscape of plastic value chain in terms of changed quantity and composition of plastics in our daily lives, waste streams, and disruptions in management of post-consumption plastic waste and recycling, and
4. Led to Single-use plastic (SUP) policy setbacks causing temporary suspension, withdrawal, delaying and/or derailing of national and sub-national (city/municipality) policies to prevent and reduce plastic pollution or reversal of enforcement of national and sub-national (city/municipality) SUP policy, putting e.g. a ban on SUPs, discontinuing the promotion of food container reuse.

The pandemic has triggered a rise in the use of single use plastic products (SUPP) in form of medical, healthcare and sanitary/ hygiene products and plastic packaging due to the surging e-commerce (online shopping and home delivery) in particular. In West Java, Indonesia, the healthcare waste generation jumped by 30% between January and April 2020. It should be noted that this increase in plastic waste had happened when the waste management capacity was possibly at a lowest point due to the restrictions on the people movement and workforce distribution in light of the safety and health concerns. Moreover, the economic slow-down brought down the crude oil price and dragged down the com-

petitiveness of recycled plastics against virgin plastic polymers, destroying some local recycling businesses. In some cities, there has been a set-back or even a reversal in policies to reduce SUPPs, such as promotion of reusable cups and cutleries in restaurants.

1.2 CounterMEASURE for Plastic Free Rivers in Asia

In 2019 the United Nations Environment Programme (UNEP), with support of the Government of Japan, started a project, later named *CounterMEASURE for Plastic Free Rivers in Asia*, to strengthen scientific knowledge on the role of rivers in plastic pollution and to support action to reduce marine plastic litter. The CounterMEASURE project works to identify sources and pathways of plastic pollution in river systems in Asia, particularly the Mekong, the Ganges and rivers in Sri Lanka. The first phase of the project generated 39 products including a framework on plastic pollution assessment and monitoring of plastic pollution in rivers in Asia, perception surveys, and tools for data collection and outreach information outreach. Close to 1,300 people took part in the Final Stakeholder Conference, 25-28 May 2020.

The second phase of the project, Promotion of action against marine plastic litter in Asia and the Pacific(CounterMEASURE II), was launched in May 2020 as the world was thrown into the pandemic whirlpool. Three strategies of the project - Policy and advocacy, Communication, and Knowledge management – actively and strategically employ cutting-edge digital technologies, including Artificial Intelligence, and partners with front-runners in digital technology and R&D in Asia and beyond, such as

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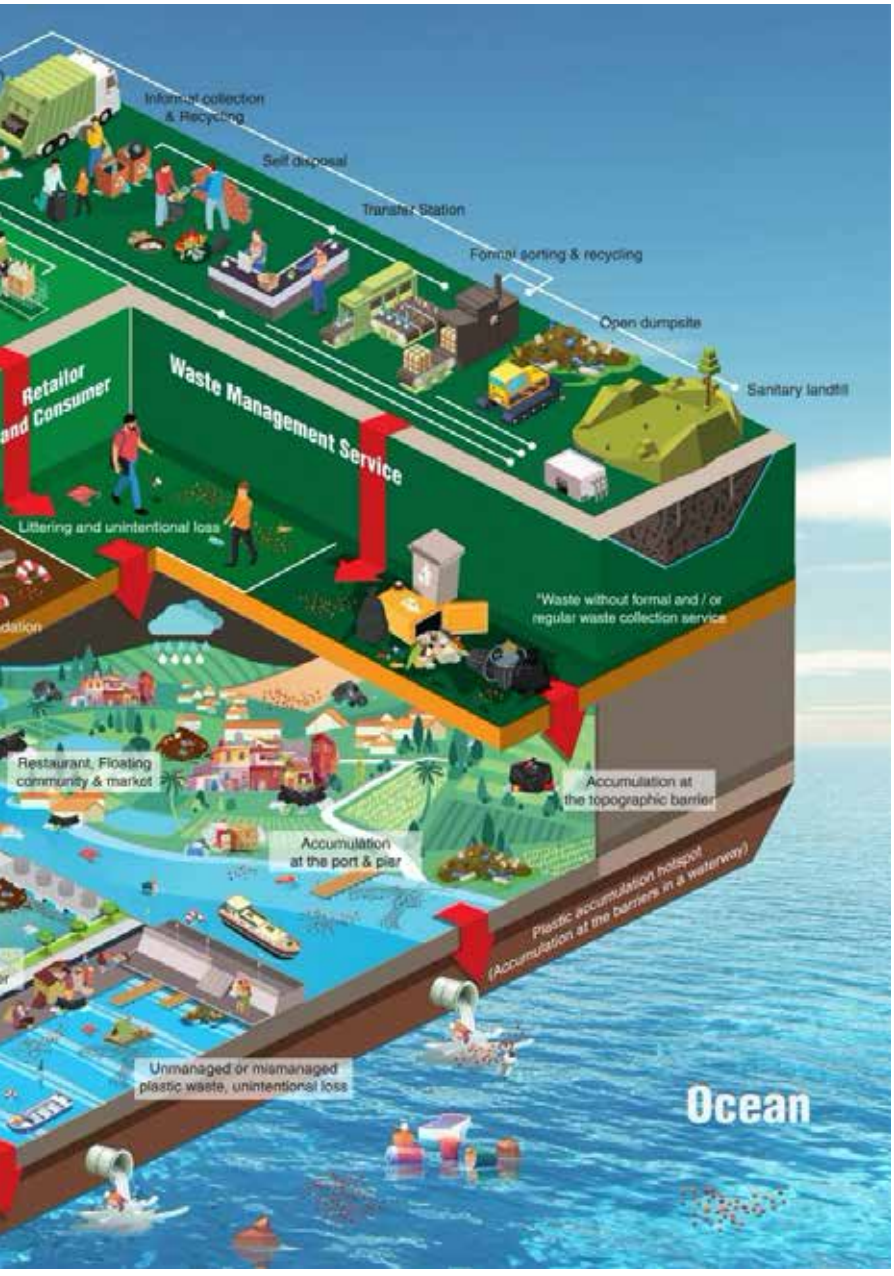


Google, Asian Institute of Technology (AIT), and Pirika Association in Japan.

Results of the CounterMEASURE project. The project identifies four types of pollution hotspots: 1) **Plastic value chain hotspot** includes elements of plastic production, conversion, trade, use and disposal. Plastic value chain hotspots are not related to any specific plastic application or product but can often be related to a plastic type (e.g., a polymer) or an industry or sector; 2) **Plastic leakage source hotspot** is identified using GIS tools with data on parameters such as population density, waste generation rate, percentage of plastic in waste stream, waste collection rate, distance to waterways and rivers, catchment run-off, slope and wind patterns. Examples: Illegal dumpsites, littering spots, areas without regular/ formal waste collection service; 3) **Plastic accumulation hotspot** is a location where waste accumulates in waterways and rivers locally and regionally. Examples: artificial barriers and topographic barriers, and 4) **Plastic application hotspot** is related to a product or packaging that is partially or completely made of plastic that is found in abundance in macroplastic (clean-ups) and microplastic surveys. Examples: disposal cutlery, multilayer food packaging, sachets (e.g. tobacco), fishing gears, items associated ave emerged, after two and a half years of work collecting plastic pollution information from over 2,000 data points in riverine cities such as Chiang Rai and Ubon Ratchathani in Thailand, Vientiane in Laos PDR, Tonle Sap and Phnom Penh in Cambodia, and Can Tho in Vietnam in the lower Mekong River Basin and Haridwar, Prayagraj, Agra and Patna along the Ganges and Yamuna rivers in India, using a mobile phone app,

and moving-camera image recognitionwith AI, and testing river waters for microplasticsthat are smaller than 5mm in diameter.

The project has found that plastic pollution characteristics are site specific. For sites along the Ganges, for example, sachets or small pouches containing chewing tobacco/ pan masala are high risk plastic items due to their abundance and difficulty in collection and sound disposal. Also confirmed is that Polypropylene is a leading plastic pollutant, as microplastic, in waters of the Mekong rivers, unlike rivers in Japan where much of microplastics in rivers come from plastics made of polyethylene. Microplastic testing in the Mekong confirms that lower parts of the Mekong, such as Can Tho in Vietnam, contain significantly more microplastic than the upper river counterparts, such as Chang Rai in Thailand. All these underlines the importance of assessment on the ground as well as development of localized solutions.

Also, before CounterMEASURE, people blamed big cities for generating most plastic waste and assumed that effort on plastic leakage reduction would be best placed in those megalopolises. However, it is now becoming more known that smaller cities with waterways and tributaries but without good waste collection coverage are also very important in reducing river plastic pollution and marine plastic litter. Waste dumping into rivers and uncontrolled dump sites along rivers are all too common in Asia. Ports and piers for cargo transport and tourism may also be key locations in effort to reduce plastic leakage. These sites not only contribute to plastic leakage through improper waste practices but accumulate plastics that leaked from upper segments of rivers. They could serve as strategic – possibly the last - intervention points to prevent plastic waste becoming pollution in rivers and ocean.

1.3 Knowledge generation and impact creation

CounterMEASURE is now demonstrating how local governments, universities and communities can come together and act on this new knowledge. In India, partners organized a series of sensitization exercises in the form of pledges, walks, workshops, clean-up events, and social media campaigns to collect vital information on plastic hotspots and leakage pathways as well as to galvanize action to curve plastic pollution. Clean-ups deliver multiple benefits: cleaning of a targeted area, public awareness raising on hazards of indiscriminate plastic use and waste disposal, generation of site-specific plastic waste data for further strengthening of the understanding, as well as verification of effectiveness of policies in place already. For example, the volunteers who cleaned up in the state where there had been a state-wide ban on use of Styrofoam containers observed near absence of Styrofoam amongst the collected waste. Cambodia, Laos PDR, Thailand, and Vietnam, served by the Secretariat of the Mekong River Commission (MRC), are preparing the Protocols for Riverine Macroplastic and Microplastic Monitoring and Microplastic Monitoring in Fish, all for long-term and cost-effective monitoring of riverine plastic debris pollution in the Lower Mekong River.

With the Convention on Migratory Species (CMS) Secretariat, the project has spotlighted the impact of plastic pollution on migratory

species such as Ganges river dolphin and Mekong Giant Catfish. On 31 August 2021, the report on “Impacts of Plastic Pollution on Freshwater Aquatic, Terrestrial and Avian Migratory Species in the Asia and Pacific Region"was launched and shared during the Ministerial Conference on Marine Litter and Plastic Pollution, 1-2 September 2021, by the Executive Secretary of the CMS. Findings of the report were covered by 63 articles in 18 countries within a few days of its launch.

In Sri Lanka, the Government of Sri Lanka has decided to strengthen measures to reduce plastic pollution in the national flagship initiative” Surakimu Ganga”. In May 2021, the National Geographic – collaborating with CounterMEASURE, ran a global story, highlighting the importance of fighting plastic pollution in freshwater bodies, such as the Ganges and the Mekong, to reduce marine plastic litter. Articles highlighting the problem of single-use plastics and the importance of reducing plastic pollution in rivers are regularly published in leading newspapers of India reaching millions.

2 Lesson Learned on digital technology application and citizen science to, and fighting plastic pollution and during COVID-19

CounterMEASURE project employs Artificial Intelligence (AI) and citizen science to scale the knowledge generation and impact creation. In April 2021, UNEP announced its partnership with Google, Geoinformatics Center (GIC) of Asian Institute of Technology (AIT) to develop a machine learning algorithm to mass detect plastic leakage on streets and in waterways to generate “heat maps”. This technology application is necessary to geo-prioritize interventions such as monitoring of fly-tipping sites, regular removal of plastic waste built-up in river banks and water canals, and development of community-level waste management plans. Statistics on waste generation and disposal in much of Asia and the Pacific are notoriously scarce. Even for cities where some official waste data exists, the temporal series of the data is short, not complete (not periodic), and/or outdated, with incomplete geographical coverage, and depends heavily on extrapolating survey data from one area to estimate similar data for larger areas. As as result, it is difficult to design interventions to reduce plastic pollution in the environment today solely replying on the existing data from the governments.

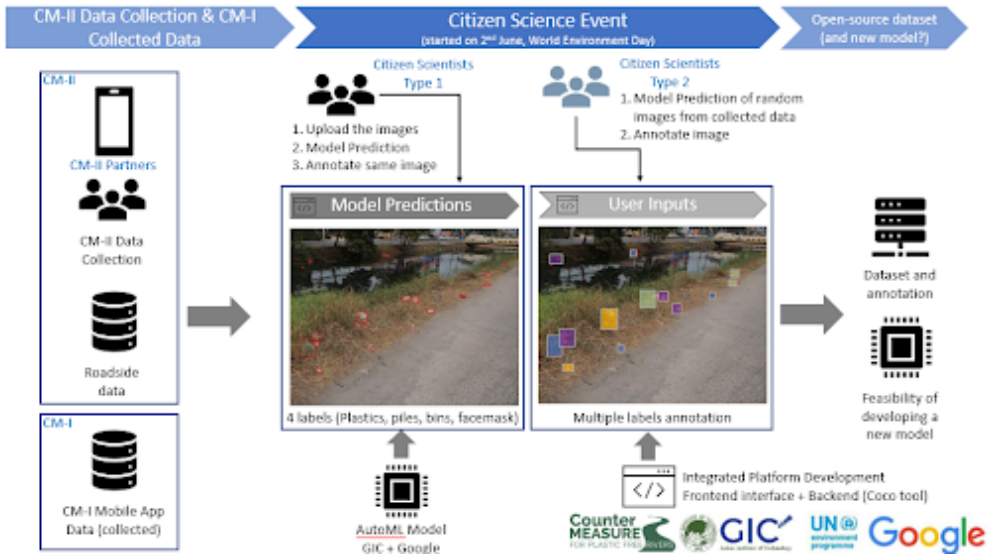
1. During the effort to develop a machine learning algorithm for the plastic leakage detection, the project’s R&D partners have faced methodological challenges such as:

2. Diversity in types of plastic objects that are site specific (not one-size-fit-all);

3. Constant addition of new plastic items into the market and in the plastic litter profile;

4. Environmental situations that make the image recognition difficult, e.g. Partially covered in soil or coated with dust, andSimilarity with non-plastic objects.

Citizen science plays a critical role in overcoming some of these challenges.The first



Citizen Science Event was organized during the week of the World Environment Day and the World Oceans Day in June 2021, to showcase how citizen science can contribute to detect plastic leakage in the community and aid the tool development. A webinar “Citizen Science and Frontier Technology in tackling Plastic Pollution in Asia”kick-started the event, highlighting multiple potentials of citizen-based plastic leakage assessment and monitoring. So far, 150 volunteers annotated images to create an open-source image database of plastic litter on streets in Asia, having received a step-by-step guide on image annotation from experts.

The model’s accuracy has significantly improved because the said partnerships and citizen support, and the resulting heatmaps, which are expected for release in early 2022 will help UNEP develop guidance for local and national governments to effectively tackle plastic pollution in rivers. These know-hows will be available soon for replication in any riverine cities with communities with plastic pollution concerns.

And, it is worthwhile to note that the pandemic induced international and domestic travel enhanced the project’s digital technology applications. When it was not possible to send experts to local project sites to conduct street image capturing, microplastic testing, or policy perception surveys, the project R&D partners developed online tutorial sessions and digital resources to guide local partners to carry out the tasks. Almost all outreach has been done virtually in form of virtual conferences, webinars, social media messaging, etc. This experience and acquired will be utilized by UNEP and its partners in designing and executing future projects and assistance.

3 .Conclusion

Like Greenhouse Gases that have altered the climate and are causing the planetary crisis, plastic pollution takes tens and hundreds of years to clear. And like Climate Change, it is a man-made problem that takes a commitment from every person, company and nation to solve.

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When an emerging technology moves from the laboratory to real-life scenarios, it needs to integrate itself into the social systems. In a like manner, when we transition to carbon neutrality and green development, we should give an in-depth thought on how to strike a balance between new technologies and urban environment, public service, and productivity enhancement. Emerging technology is a double sword. It is inevitable to undergo a running-in period in the course of application and integration. How to help cities, including communities, make technologies more of a blessing is what all stakeholders should bear in mind. The focus of this chapter is regional practice. We aim to draw experience from the practice of Germany, Denmark, China, and Singapore and search for a technology-promoting mode that can be generalized and scaled. This part provides readers superstructure strategic thinking and practical tools for implementation. Methodological tools as Urban Living Labs are also introduced.

CHAPTER THREE:

EMERGING TECHNOLOGIES AND APPLICATION SCENARIOS

Urban Living Labs for the Green and Digital Transition

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Institute of New Economic Development

On September 22, 2020, Chinese President Xi Jinping announced at the general debate of the 75th UN General Assembly that China aims to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060. Compared with advanced economies who have announced carbon neutrality goals, the following three factors have increased the challenges China facing. First, the time has been significantly shortened. The average time interval from carbon peak to carbon neutrality of economies making the commitments is about 45 years and that of most developed countries is more than 50 years, while that of China is 30 years. Second, China bears a large amount of "hidden carbon" emissions that should belong to other countries. As a "world factory", China has produced massive products consumed in other countries. Statistics show that the total amount of "hidden carbon" undertaken by China in 2015 exceeded 80% of the total amount of "hidden carbon" retained by all OECD member countries in other countries. Third, compared with developed economies, China is still in the process of accelerating industrialization and urbanization, and China's 14th Five-Year Plan clearly sets the goal of per-capita gross domestic product will reach the level of the middle ranks of developed countries. However, from past experiences, carbon emission would increase with per-capita GDP growth.

The carbon neutrality commitment reflects China's vision to promote the construction of a community of common destiny for humanity and implementation for the UN 2030 Agenda for Sustainable Development, while realizing people's aspirations for the good life is the fundamental goal of China's economic and social development. New approaches are needed to achieve all these goals simultaneously, and thankfully the digital economy is creating more possibilities.

From the experiences of global cities pioneering in green development and low-carbon transition, urban living labs (ULLs) are emerging as a form of governance experiments for both green and digital urban transitions. ULLs are usually set up to address specific challenges and operated by a diversified partnership including participants such as governments, research institutes, private companies and social organizations. ULLs test new technologies, products and business models as well as their impacts in real-world environments by conducting experiments including standards steps such as project design, process implementation, outcome evaluation and user feedback, which facilitates the validation, diffusion and incubation of innovations.

©**Figure 1 Key Elements of Urban Living Labs**

his article introduces practical experiences of urban experiments and ULLs from Manchester, Austin, and Chengdu, and propose an idea of sustainable metaverse.

1.Manchester Oxford Road Corridor: Building Adaptive Learning Community

In 2003, the United Kingdom government's Department of Trade and Industry published *The UK White Paper on Low Carbon Economy* (UK DTI, 2003), calling on local and regional governments to develop demonstration and pilot projects to reduce carbon emissions while raise the rate of sustainable economic growth. This encouraged the initiative of the Manchester Oxford Road Corridor Urban Living Lab (hereinafter referred to as "the Corridor Lab"). The Corridor Lab covers an area of 2.43 square kilometers from St Peter's Square in the central business district to Whitworth Park at the southern extent of the University of Manchester. At that time, this narrow corridor with world-class universities, science and technology zones and NHS foundations had just experienced the economic revitalization of the city center in 1990s, and contributed 22% of the gross domestic product of the whole city. It was the area where Manchester high value-added industries gathered and had the most intensive and active economic activities. However, with the rapid economic growth, there are also a series of environmental problems, such as lack of green infrastructure, traffic congestion, air pollution and noise. Shifting from rapid economic growth at the expense of the environment to a green and low-carbon development model requires a brand-new urban experiment.

In 2008, Manchester City Council, University of Manchester, Manchester Metropolitan University and Manchester Central Hospital NHS Foun-

©**Figure 2 Manchester Oxford Road Corridor**

dation Trust officially entered into a partnership, with a total investment of £ 1.5 billion planned over five years mainly for (1) transportation; (2) environmental governance and infrastructure construction; (3) research and innovation; (4) employment, business communication and skills training; (5) sense of place, which aims to turn the Corridor into a "physical global exemplar of knowledge based growth". Since the establishment of the partnership, the Corridor area has been set as an urban living lab. Stakeholders have reached a consensus on allowing environmental monitoring sensors to be installed in the area, testing new applications for carbon reduction, and usage of the data collected for research purpose.

i-trees is a representative project of the Corridor Lab. This project was conducted jointly by Manchester City Council, University of Manchester and Red Rose Forest. Nine experimental plots were set up within the Corridor, and different formation of trees and surface-cover types were tested at each plot. Meanwhile, environmental monitoring sensors were installed to collect data, so as to study the impacts of different landscape forms on carbon emissions, microclimate and hydrology. i-trees is then extended to the study the impacts of planting tree in different soils, using different species and planting at varying distances from roads. As for work assignments, the city council and the charity are mainly responsible for propagandizing the vision of the project, getting residents' supports, and managing potential risks, while the university is mainly responsible for project design, implementation, evaluation and future research initiation.

The Manchester Oxford Road Corridor uses ULL to form a public-private partnership to promote regional green and low-carbon development and urban renewal. Through the

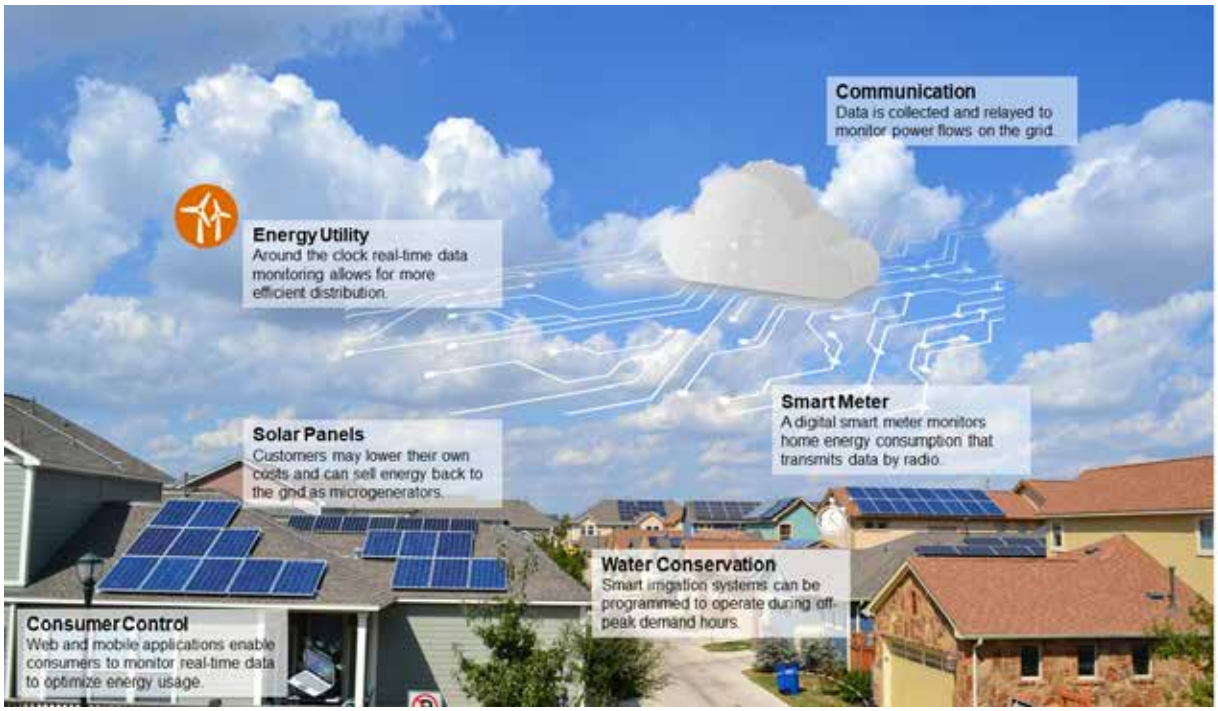
reconstruction of physical infrastructure, the installation of digital infrastructure and the design of multi-cooperation mechanism on data, a prototype of value creation based on regional adaptive learning is created. In terms of construction and operation, the main participants in the construction of the lab are also the main landowners of the region, which facilitates the conduction of innovation experiments in the urban area. In accelerating innovation diffusion, the lab builds bridges between the city's innovators and administrators in the following way: the data and facts from the real-world experiments provide basis for more accurate policy making which in term might foster a more compatible environment for adaptation of innovations. It is shown by the results that the Corridor Lab suffered from problems which are common in ULLs, such as data usage and data security, lack of inclusion due to elite management group, and no direct economic benefits like the formation of green and low-carbon business cluster.

2.Austin Pecan Street: Born for Smart Grid.

Coincidentally, in 2003, the then president of the United States, George W. Bush, out of consideration for national security and economic security, proposed to promote the modernization of the electric delivery system as soon as possible. In July of the same year, the U.S. Department of Energy (DOE) launched the "Grid 2030" Plan. The plan points out that the aging electro-mechanical electric grid cannot keep pace with innovations in the digital information and telecommunications network, and the integration of energy technology and digital technology will probably give birth to the most advanced power system in the world. Since then, the U.S. government has launched a series of policies and measures to accelerate the process. In February 2009, the successor U.S. President Barack Obama launched a $787 billion economic stimulus package, entitled the American Recovery and Reinvestment Act (ARRA) of 2009, of which $4.5 billion was dedicated to supporting the development of smart grid. Building smart grid after the financial crisis incorporated the expectations of boosting the economy and helping the United States get rid of its dependence on fossil fuels and transform into a green economy. Pecan Street Urban Living Lab (hereinafter referred to as "the Pecan Street Lab") came into being at this very moment.

The Pecan Street Lab originated from the "Energy Internet Demonstration" project launched by DOE, which is earmarked for smart grids by ARRA 2009. Affiliated to the urban renewal project of Mueller Community in Austin, Texas, the laboratory covers an area of 711 acre, aiming at testing and promoting various electric vehicles, solar panels, home energy management systems (HEMSs) and numerous other smart technologies in urban communities, propelling the community to achieve net zero carbon emissions and creating green collar job opportunities.

The Pecan Street Lab is initiated by Pecan Street Inc. and is jointly built with the City of Austin, University of Texas at Austin, Austin Technology Incubator, Austin Energy, National Renewable Energy Laboratory and Environmental Protection Fund and other industry partners. Diversified participants form



©**Figure 3 Austin Pecan Street ULL model**

a multi-dimensional partnership to promote R&D, demonstration, application, and commercialization of new technologies. The lab continues to expand partners' network and grew into a source of smart grids innovations and applications serving the world.

About 1,200 households and businesses in Mueller community voluntarily participated in the Pecan Street Lab urban experiments. These users have reached agreements on the following three aspects: first, install digital sensors to continuously monitor their energy consumptions; second, try out new technologies and products for smart grids and smart homes; third, authorize the usage of data for research and other application tests generated by the Lab.

A representative experimental project is to install household energy storage systems to ease power supply pressure during peak hours and utilize renewable energy efficiency so that to reduce carbon emission. A total of 67 households participated in the project, and each household was equipped with 20 kWh lithium-ion battery system. The project lasted from October 2012 to September 2013. Monitoring data presented that electricity consumption peak was from 6: 00 pm to 9: 00 pm, while wind power production on the ERCOT(Electric Reliability Council of Texas) grid used by the community was from 10: 00 pm to 5: 00 am. Thus, residents' electricity consumption peak was the batteries' discharging time, while the period of wind power generation was the charging time. The experimental results showed that the installation of energy storage batteries has reduced the carbon emissions of 67 households by nearly 200 kg a year, while each household still has varying degrees of battery remaining. If users are guided to improve their electricity consumption habits and the smart grids are further optimized, the experimental would get much better results.

Compared with the Corridor Lab, the Pecan Street Lab is much more effective in facilitating green innovations and driving economic

growth, which attributes to the following two strategies. The first is data usage. Pecan Street has been collecting energy data from volunteer homes for more than a decade and build the world's largest resource for residential energy use data, which has been used by more than 2,000 researchers from 60 countries, and helped decision-making of private and public sectors as well. Then it's about platform construction. Smart grids as new energy infrastructure, provides testbed and gathering platform for various HEMs new applications. The lab not only leverages agglomeration function of smart grits but also facilitates innovations' entrance into the real-world scenarios via its partnership with community residents. There is no wonder that leading enterprises such as Intel, Dell, 3M, Sony, Siemens and Schneider are members of the Pecan Street's Industrial Advisory Committee and continuously sponsored the program.

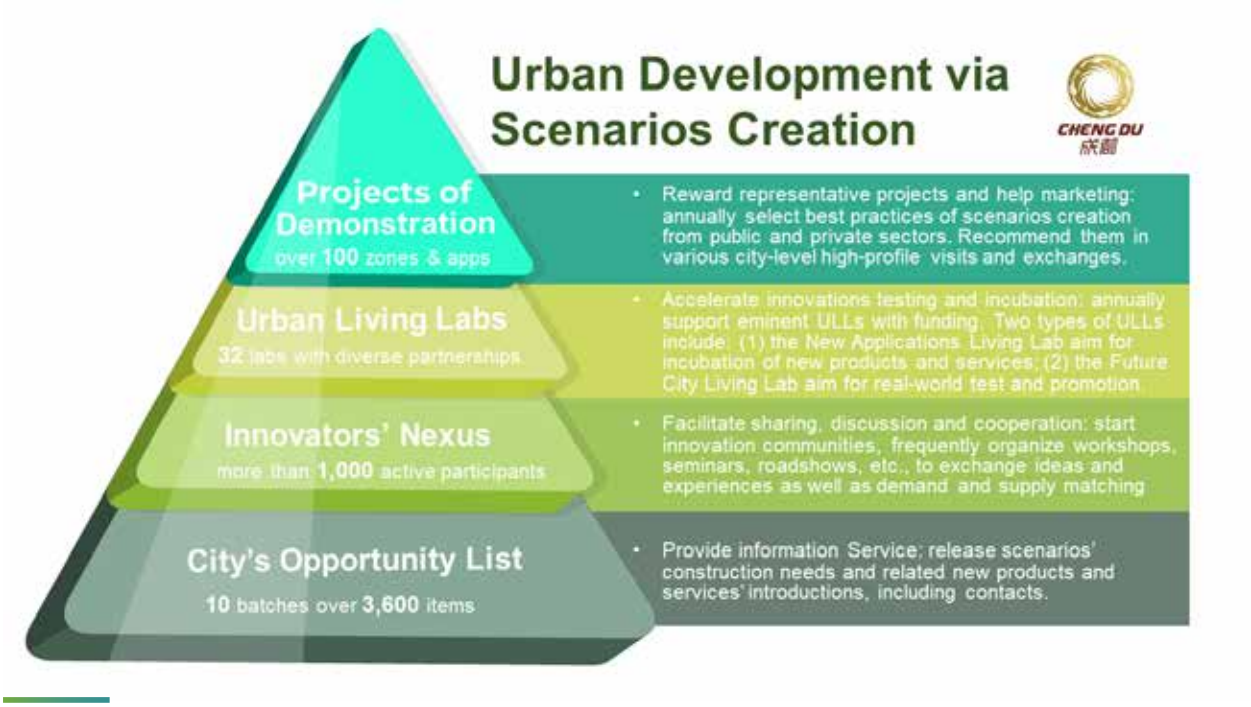
Most cases exploring ULLs for green and low-carbon transition suffer from several common problems. For example, the lab is limited to certain area, usually a street or community, and lacks a systematic design at the city level. The experiments are overly techno-centric and do not engage enough local populations of contexts, which caused inclusion challenges. Seldom attention is paid to the Nature-based Solutions (NbS), with funding being a major obstacle.

It would be folly to set up a program under which research in the natural sciences and medicine was expanded at the cost of the social sciences, humanities, and other studies so essential to national wellbeing.

Vannervar Bush, Science: the Endless Frontier

3.Chengdu Urban Scenarios Creation System : from City of Opportunities to Park City

In 2016, AlphaGo defeated a human champion in the game of Go; founder of the World Economic Forum Klaus Schwab coined the Fourth Industrial Revolution (4IR), which described the stage of new technological progress the world undergoing characterized by the convergence and complementarity of emerging technologies such as artificial intelligence, human-machine interfaces, nanotechnology, biotechnology, as well as integration of physical and virtual worlds. Just as each industrial revolution is bound to experience, how to promote the adaptation of digital technology



©**Figure 4 Chengdu New Economy's Scenarios Creation Toolkit**

innovations and real demands is the key to unleash the potential of the new revolution.

Chengdu, an inland city from China, is conducting a systematic urban experiment.

In 2017, Chengdu set up a special government agency, the Chengdu New Economic Development Commission (NEDC), to help the diffusion of digital innovations in all parts of the city. Chengdu has enriched and extended ULLs methods and systematically proposed *urban development via scenarios creation*, which integrates supply and demand via application scenarios and constructs a pyramid model to encourage iteration and upgrade of new solutions. The NEDC has launched a scenarios toolkit including four layers: **a city's opportunity list, an innovators' nexus, two types of ULLs, and three sets of demonstration projects**, which implements the functions of information service, facilitating sharing, discussion and cooperation, supply and demand matching, tests and incubation, as well as marketing respectively. By June 2022, Chengdu has released more than 10 batches of opportunity lists containing over 3,600 items, formed an innovation nexus of over 1,000 active members of diverse backgrounds, selected 32 urban living labs, and awarded more than 100 demonstration projects.

Via scenarios creation, Chengdu builds channels for innovations to enter the real world and help innovative MSMEs to attract talents and capital; the scenarios' policy toolkit provides general solution for new urban challenges. Along with the idea of City of Opportunities is gradually realizing, the city is pursuing the shared expectation of carbon neutrality.

In the process of building Park City and promoting urban green and low-carbon transition, Chengdu deploys scenarios creation methods in the following three ways. First, the city released the City Opportunity List of *Park City Demonstration Area Construction*, the first batch of which includes more than 1,000 scenarios construction needs, such as ecological restoration, pollution prevention, resource recycling, and green emerging technologies incubation. **The list also integrates inclusive considerations into green transformation, including old-age care, childcare, and health care.** Then the city intensively uses Nature-based Solutions, while embedded consumption and industrial scenarios in the urban green networks to share the costs of NbS management and maintenance. According to official data, by April 2022, Chengdu has built a total of 5,327 kilometers of greenways. By construction culture, entertainment, and sporting scenarios along the greenways, the total amount of tourists can reach tens of millions of people. The value conversion from

©**Figure 5 Inclusive considerations in Chengdu's scenarios creation.**

ecological to economic is foreseeable.

Besides the above, Chengdu has conducted scenarios' experiments of the following three types. One is the near-zero carbon emissions scenarios assembled green technologies, like the Tianfu CBP Headquarter Base Near-zero Zone. From the beginning of its construction, big data, IoT and other technologies have been deployed to analyze and predict the carbon emissions of the zone and make carbon emission reduction plan. A second is the sustainable agriculture scenarios. For example, high standard farmland is being built encircling the city via backfill with fertile soil, soil thickening, organic fertilizer, nitrogen-fixing plants, biopreparate, straw turnover, etc. The total crop output is expected to exceed 20,000 tons in 2022. A third is individual carbon credit scenarios. On a program called Tan Hui Tianfu and its partnering platforms, citizens can set up personal carbon accounts, obtain carbon credits by carrying out emission reduction and low-carbon activities in daily-life scenarios, and redeem green goods and services provided by the program.

©**Figure 6 NbS is intensively deployed in urban development of Chengdu.**

4.Implications and Suggestions

Around the world, ULLs are emerging with various goals, sponsors, partnerships, and operating models. For the ULLs set up to drive low-carbon transition, achieving carbon neutrality is a shared vision worth all efforts. Thus, shall we have a global digital platform like Facebook, Amazon and Tiktok, which can turn sustainable development, green low-carbon and carbon neutrality into fashion trend, street talk, or daily life?

Upon the Nature-based Solution and green innovations driving by digital technologies, we have an idea of convergence of the two approaches, that is, expand the NbS to "green metaverse" via artificial intelligence, blockchain, virtual reality, satellite Internet, etc. By

#	Name	Location	Cover Area	Key Partners	Main Scenarios
1	Oxford Road Corridor	Manchester, UK	2.43 km²	Manchester City Council, Manchester University, Manchester City University, Manchester Central Hospital NHS Foundation Trust	• Transportation • Environment • Research and innovation • Business • Sense of place
2	Pecan Street	Austin, USA	2.87 km²	Pecan Street Inc., the City of Austin, University of Texas at Austin, Austin Technology Incubator, Austin Energy, National Renewable Energy Laboratory and Environmental Protection Fund	• Smart grid • Home energy management system • Smart home
3	Urban Scenarios Creation System	Chengdu, China	whole city	the Municipal Government, Chengdu New Economic Development Committee, diverse participants from public and private sectors	• Broad digitalization • NbS and near-zero • Inclusion • Sustainable agriculture • Carbon credits

©Figure 7 ULLs' Cases Summary

applying the combination of online flow, capital and carbon credits, the metauniverse realizes the value creation and exchange, and has the following three main functions:

1. Display ULLs cases and enable simulation construction, exchange of experiences and cooperations;

2. Facilitate green products and services' innovation, tests, promotion and transaction;

3. Design, initiate and implement green activities and carbon reduction actions.

The way to achieve carbon neutrality in real world is arduous and long. However, the digital era might provide us with a chance, which people all over the world join hands to experiment in the virtual world to achieve carbon neutrality and build a green planet where we share prosperity.

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Four dimensions for systematic promotion of carbon neutral urban development: Lessons from Germany for Cities to consider

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More and more countries around the world have come to the conclusion that it is inevitable to address climate change by achieving an overall goal of sustainable development. Understanding and implementing the new development concept of innovation, coordination, green, openness and sharing has become one of the most important themes of international exchange and cooperation. The international community needs to work together to promote a "green recovery" of the world economy after the pandemic and to gather a strong synergy for sustainable development. In doing so, they also provide ways of inspiring urban managers and city leaders to adopt these initiatives to strengthen their approaches to carbon neutral systems.

The findings of a number of German and international think tanks show that we need more renewable energy, rapid market growth of batteries and thermal storage systems, Power-to-X and all other available technologies to achieve climate neutrality. And while many of these technologies are ready for market adoption or simply need to be scaled up, there is also a large number of innovative technologies that are still in the experimental stage.

But the application of these technologies should not exist in isolation. More than two decades of German experience with the energy transition, have shown that the overall climate goal can only be achieved if all areas of action are transformed. In between these areas, the focus of technology measures can be somewhat shifted: For example, emissions reduction may be achieved by reducing final energy demand or by shifting to climate-neutral energy sources. However, if the transition pathway relies too much on just a single area of action, a holistic goal will ultimately not be achieved.

Therefore, in its interim report "dena Leitstudie II - Towards Climate Neutrality", the German Energy Agency (dena) proposes a four-pillar strategy for achieving climate neutrality:

1. improving energy efficiency;
2. increasing the use of renewable energy sources directly as primary energy sources (renewable electricity and bioenergy);
3. preparing gaseous and liquid zero-carbon power fuels from renewable energy sources (PtX); and
4. "negative emissions" from the atmosphere through active capture or absorption of CO_2.

To achieve climate neutrality, the pace of implementation needs to increase significantly, and the necessary measures must be advanced as quickly and consistently as possi-

ble. For example, numerous studies and analyses show that energy efficiency measures can be considered mandatory in all areas.

The above experiences have implications for carbon neutral urban development on a global scale. As a major source of carbon emissions, cities face many issues: How to

1. coordinate various sustainable development goals including climate goals,
2. integrate the four pillar strategies and develop a reasonable carbon neutral development pathway map,
3. ensure high quality implementation of carbon reduction measures as well as innovative technology approaches, and
4. generate sustainable impact through innovative and pilot demonstration measures.

Promoting carbon neutral development requires systematic programs, and the urgency of climate change requires that these programs are implemented at scale as soon as possible. The following four dimensions can help cities and policy makers develop systematic work programs that facilitate the application of new approaches, technologies and models at scale.

1. Visionary goals
2. Route maps and planning
3. Implementation measures and
4. Policy Framework

In the following paper, we will use some specific cases to illustrate how policy makers and urban managers in cities can promote urban carbon neutral development systematically and at scale by starting from using these four dimensions.

1.Constructing Visionary Goals

The 2030 Agenda for Sustainable Development and the Paris Climate Change Agreement, adopted in 2015 did lay the foundation for a new development paradigm for the international community: to achieve shared prosperity for people and the planet in the frameworks of partnership and multilateralism. These two frameworks, although negotiated and adopted under different multilateral processes, are highly relevant to each other. A 2018 commissioned study by the German Federal Ministry of the Environment shows that there are interactions between different areas of climate action and most of the SDGs, and that most of these links are mutually reinforcing.(See Figure 1.) For cities, understanding the relevance of the two frameworks and developing clear visionary goals based on their positive interaction with each other can help city management to better face multiple challenges such as climate, health or economic crises, to develop coherent policy planning, and to improve the efficiency of implementation.

Figure 1 Interaction between climate action in different areas and the SDGs (Source: Gonzales-Zuñiga et al., SCAN tool: Linking Climate Action and the Sustainable Development Goals - Key findings note, available online: https://ambitiontoaction.net/wp-content/uploads/2019/04/Key_findings_final.pdf, 2018)

2.Case Studies

2.1 Case study 1: Urban Sustainable Development Goals Indicators

The "SDG Indicators for municipalities" is a system of indicators developed by the German Institute for Urban Affairs (Difu) and seven partner institutions for counties, towns and municipalities with a population of 5,000 or more. Its main purpose is to identify suitable indicators and provide data for assessing the implementation of the Sustainable Development Goals at the city level in Germany. The 2020 update of the system includes 120 indicators, which are systematically organized using a modular structure. The selection and use of the indicators can be decided by the participating cities according to their local conditions.

Take, for example, the local sustainability report completed in 2020 for the city of Bonn, Germany. The report selects 46 out of the 120 indicators to assess local developments in the six thematic areas of "Transport, Climate and Energy, Natural Resources, Work and Economy, Social Participation and Gender Equality, Global Responsibility and One World" and shows how relevant they are to the achievement of the Sustainable Development Goals in Bonn. The analysis of the report shows that 17 indicators are directly related to SDG-7 "Affordable and Clean Energy" or SDG-13 "Climate Action". Of these, 16 are concentrated in the three thematic areas of "Transportation, Climate and Energy, and Natural Resources" and one in the thematic area of "Work and Economy. For the "Transport" category, The report shows that Bonn's residents adopt a higher proportion of *green mobility* (walking, cycling or public transport) than the average German city for the overall choice of transport. However, the density of motor vehicles in Bonn has remained almost constant since 2015. This hinders the overall positive development of the CO_2 balance in Bonn. Thanks to successful municipal climate protection policies, Bonn's per capita CO_2 emissions have been reduced by about 25% from 1990 to 2016, as shown in the category of “climate and energy”. The share of renewable energy in municipal electricity supply (72% in 2018) is leading the way in Germany and is set to expand further. In the category of "natural resources", about half of Bonn's urban area is protected, the growth rate of residential and transport land area is smaller than the population growth rate, and the supply is sufficient. However, the increased consumption of drinking water due to high summer temperatures and climate change pose new challenges for the city of Bonn. Overall, the report is oriented towards the community and presents developments in the various subject areas in an easy-to-understand manner that enhances the transparency of information. Through a concise beacon system, the report shows where the City of Bonn has made progress in recent years, where there are weaknesses and where policy measures need to be readjusted. At the same time, the report provides concrete municipal data and findings for the city of Bonn to learn from each other and to improve communication with other cities on a national and international level.

The portal of “SDG indicators for municipalities”, www.sdg-portal.de, received the UN Sustainable Development Goals Action Award in 2019.

Figure 2: Energy and Climate Protection Management
(Source: dena)

The content of the website not only displays indicator data from thousands of cities, but also includes about 200 examples of good practices for cities to reference and learn from.

Road map and planning

A suitable road map that cities can adopt, needs to meet three conditions:

1. it can achieve the vision goals;
2. it is at the same time flexible enough to adapt to social changes and technological developments; and
3. it has the understanding and support of key stakeholders.

The second and third points are particularly important in the process of carbon neutral urban development. Achieving climate goals requires maintaining technological openness. Research on Germany's energy transition pathway shows that a technology-open pathway is more relevant and beneficial from a national economic perspective than a single pathway, such as full electrification. Therefore, cities need to develop locally tailored pathways and planning schemes that provide a framework for promoting innovation and incorporating new technologies. At the same time, in the development and implementation of pathways and plans, city decision makers need to coordinate with all relevant departments to complement the overall effort, enhance stakeholder communication, and focus on increasing public participation.

2.2 Case study 2:Urban Energy and Climate Protection Management System

The Energy and Climate Protection Management System (Energie- und Klimaschutzmanagement; EKM) is a management tool developed by the German Energy Agency for German cities and towns and applied in pilot cities and towns since.

2010. It covers buildings, energy, transport, water and waste treatment, with the aim of improving energy efficiency and achieving sustainable development in cities and towns. The focus is on overall energy optimization in the municipal action area, rather than on the implementation of individual measures.

The EKM is a dynamic cyclic system consisting of six linked segments (steps), for which pilot cities that successfully implement the EKM system are certified upon acceptance. During the three-year project period, the German Energy Agency supports the selected pilot cities in introducing the management system and implementing the initial measures. More than 50 German cities and towns have already implemented the energy and climate protection management system, 13 of which have been certified and honored by the German federal government. In addition, the management system has been applied in Russia (36 municipalities), China (25 municipalities), Ukraine (2 municipalities) and Kazakhstan (1 municipality). In international cooperation, the EKM system is adapted and optimized to the framework conditions of each country.

The city of Magdeburg, Germany, can serve as a typical example of a German town applying EKM: It isn't necessarily one of the bigger cities with approx. 230,000 inhabitants, but big enough to be home to a university of approx. 18.000 students. The city has a long history, dating back to before the medieval times. Formerly known as "City of Heavy Engineering", Magdeburg now focuses on environmental technology, circular economy, as well as on the health industry and logistics, in addition to the mechanical and plant engineering industry. With the Otto von Guericke University, the Magdeburg-Standard University of Applied Sciences and many renowned scientific and research institutions the city of Magdeburg has become an internationally recognized location for science and research. This is complemented by the transformation of the old commercial port into a modern "science port" with a think tank, innovation and entrepreneurship center.

Since 2010, the city of Magdeburg has been preparing for the application of the Energy and Climate Protection Management System, establishing the corresponding organizational structure, defining the general coordinator of the work and starting to develop the "Energy and Climate Protection Plan for Magdeburg 2013-2015". The goal of the first phase was to reduce energy consumption by more than 5% in the same period. Based on a comprehensive analysis of the city's energy situation, the plan included a total of 17 measures from the areas of buildings, urban planning, electricity use, transportation, energy systems and communications. In April 2013, the city council adopted the energy and climate protection plan and officially started working on its implementation, which already included energy-saving renovations and a new day care center, the installation of a

combined heat and power plant (CHP) at the Diesdorf swimming pool and energy monitoring in some municipal buildings. This work continued with the implementation of energy monitoring from 2014 onwards, as well as a climate protection portal of the City of Magdeburg (active since 2014), presenting information on the numerous policies, implementation projects and activities for climate and the environment in Magdeburg.

Implementation Measures

Guided by the visionary goals and the roadmap planning, the implementation measures are the most challenging of the four dimensions for cities. This stage is not just about implementing individual pilot projects using innovative technologies and ideas: While pilot projects are the most direct way to test technology ideas and provide first-hand information for content validation and iterative optimization, the development process of carbon neutrality will involve innovative technologies at different stages as well as an overall commitment to be innovative and ensuring a range of diverse stakeholders and partners are involved, including the less usual suspects. Whether the innovative technologies are ready for market application or still in the experimental stage, their implementation measures require stakeholders or direct participants, such as government, enterprises, research units, incubators and exchange platforms, to clarify their roles and tasks while working together closely. Ultimately, the participating parties will be able to transform innovative ideas and technologies into replicable and scalable new models and new business models such as standards, processes and competency training methods through pilot projects, which in turn will promote the overall development of the market.

2.3 Case study 3:Integrated retrofit of assembled existing buildings

In order to rapidly increase the rate of retrofitting existing buildings in Germany and overcome the severe shortage of professionals in the building market, the German Energy Agency, with the support of the German Federal Ministry of Economics and Energy, started a feasibility study and preliminary preparations for the market launch of the EnergySprong model in Germany in 2017. EnergySprong is a comprehensive retrofit model for existing buildings that achieves "net zero energy" in one stage through multi-technology integration and model innovation. Its main advantages are: digital, high-quality retrofitting according to net-zero energy standards, prefabrication and multi-technology integration that significantly reduces retrofitting time,

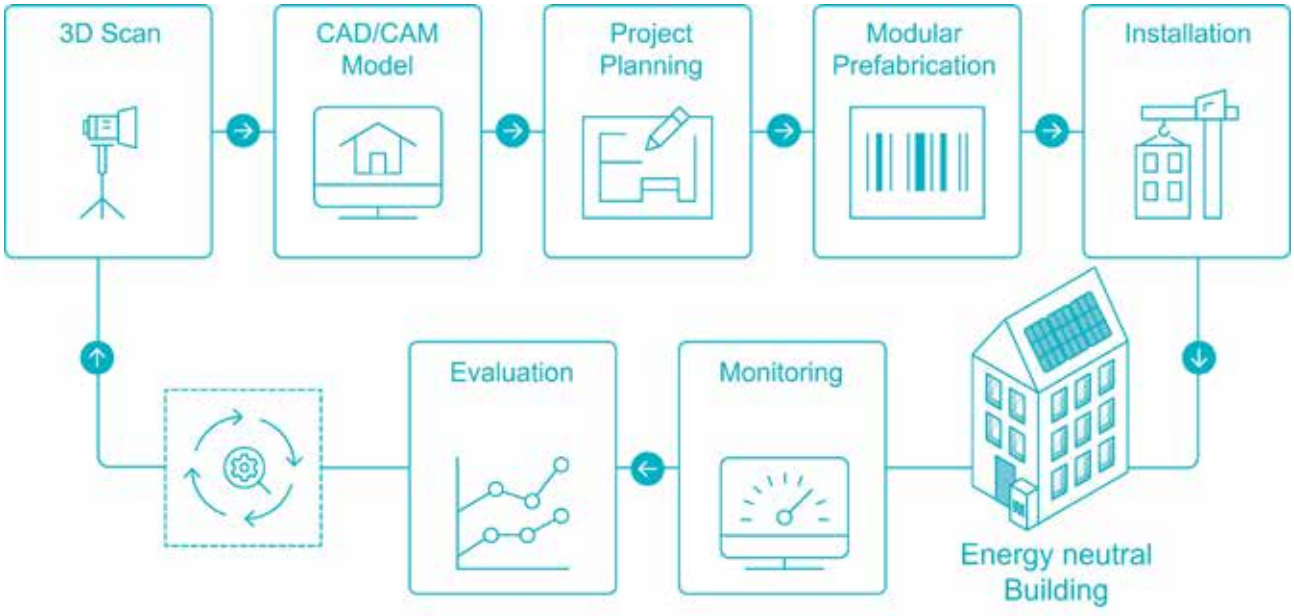

Figure 3 EnergySprong Model Retrofit Process
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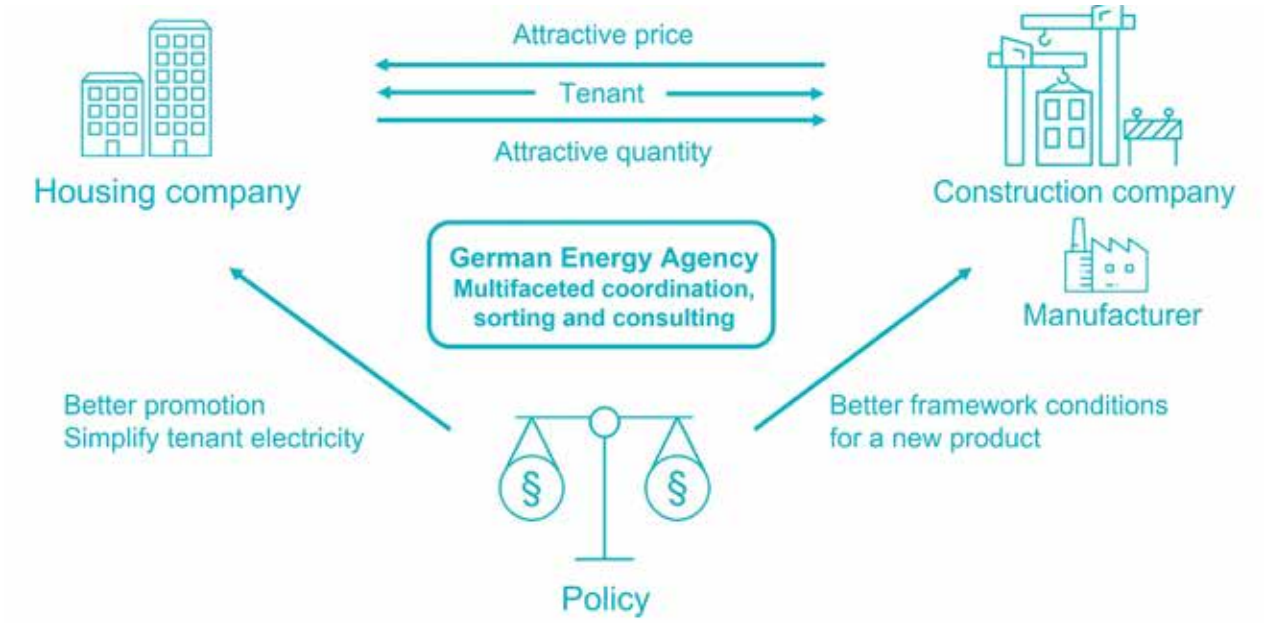

Figure 4 Role of the Market Development Team in the EnergySprong Model Rollout
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significantly improves building comfort and uses innovative financing methods.

The EnergySprong model was developed, tried and tested in the Netherlands in more than 1,000 single-family or attached houses. However, the bottleneck in the early stages of market introduction in Germany was how to coordinate the efforts to drive market demand, promote technology development and establish a business model by connecting the various participants and stakeholders. Therefore, one of the most important tasks in the initial preparation is market development. The German Energy Agency has formed a dedicated market development team for this purpose as a neutral platform to drive the development of new integrated retrofit solutions together with innovative companies from the real estate industry, construction companies, facade, PV roof and building technology module manufacturers.(See figure 4)

After extensive preparatory work, 22 real estate companies and five building integrators in Germany confirmed their participation in the EnergySprong scale up pilot project. The number of participating companies is growing, and the first integrated retrofit pilot projects was officially launched in November 2019. By 2023, 11,635 apartments across Germany will have been retrofitted with the EnergySprong model of net zero energy under the overall coordination and support of the German Energy Agency. At present, the EnergySprong model has gained great attention in the international field. In addition to the Netherlands and Germany, pilot and extension work has been carried out in France, the UK, Italy, the US and Canada.

2.4 Case study 4:Climate friendly building for the future

Buildings are tied with industry and transportation as the three main areas of energy consumption, with end-use energy consumption for building construction and operation currently accounting for more than one-third of total global energy consumption. This also subsumes to nearly 40 percent of total direct and indirect CO_2 emissions. Driven by improved access to energy in developing countries, the use of energy-consuming equipment, rapid growth in global floor space, the overall energy consumption in the building sector will continue to rise. The development of climate-friendly buildings therefore plays a crucial role in addressing this challenge.

Since 2006, the German Energy Agency and the Ministry of Housing and Urban-Rural Development of China have been working together at the policy and technical levels to

Figure 5 Hebei Research Institute of Building Science in Shijiazhuang

promote energy efficiency in China's buildings. As a result of the cooperation, a series of passive low-energy building demonstration projects have been implemented. These do not only improve the energy efficiency level of the project buildings, but also promote the introduction of relevant local standards and incentive policies, by drawing on German energy-efficient building standards and design concepts. The German Energy Agency makes sure that these solutions are adapted to different geographical and climatic characteristics of China.

In 2006, when the cooperation started, the concept of ultra-low energy buildings was still brand new in China, and there were no relevant standards and policies. Even the core technology of ultra-low energy buildings was not well understood in the construction industry, and there were only a few professionals who were capable of implementing ultra-low energy building projects. Following the signing of a Memorandum of Understanding on cooperation between the German Energy Agency and the Center for Science, Technology and Industrialization Development of the Ministry of Housing and Construction in 2008, the first batch of Sino-German passive ultra-low energy building demonstration projects were officially launched in 2010. The cooperation between the two sides subsequently moved from the theoretical exchange stage to the actual project practice stage.

The increasing number of demonstration projects since the start of the partnership has also contributed to the growth in demand for related technical consulting and quality assurance services. In order to ensure that the core indicators and requirements related to energy-efficient technologies and quality and quality are effectively adhered to and implemented during the design and construction process, the demonstration projects require a quality assurance system for the entire process. This system includes several important aspects such as design training, design guidance and review of drawings, construction training, construction site inspection, completion acceptance and in the end a quality mark certification.

By the end of 2020, 47 demonstration projects have been implemented (29 completed) in 12 provinces and 4 climate zones in China. The building types and functions of the demonstration projects are diverse, ranging from schools and kindergartens, to high-rise residences and villas, to office buildings and pavilions.

The R&D center project of Hebei Research Institute of Building Science in Shijiazhuang is the first Sino-German demonstration of passive low energy office building, which was completed and put into use in 2014. The project uses an integrated ground-source heat pump cooling and heating system and terminal linkage to efficiently address the needs of cooling, heating and fresh air systems. Compared with the mandatory 65% energy saving rate of new public buildings in Hebei Province, the energy saving rate of this project is over 90%, and it can reduce 596 tons of carbon dioxide emissions per year.

In the demonstration project of the office building and apartment building of CECC Chengdu located in Chengdu, Sichuan Province, the development, production and use

of new energy-saving prefabricated components were pioneered. Successfully trying here, the organic combination of passive ultra-low energy technology and prefabricated reinforced concrete component technology has been successfully accomplished. This has played a demonstration role in breaking the existing technical barriers and expanding the diversity of future implementation options.

The practical experience of demonstration projects has significantly contributed to the formation of the technical standard system for ultra-low energy buildings in China. Hebei, Shandong, Beijing and other provinces and cities, which have carried out the earliest and most demonstration projects, have taken the lead in introducing several standards and technical guidelines related to ultra-low energy buildings. This might include documents such as the Technical Guidelines for Ultra-Low Energy Demonstration Projects in Beijing released in 2018 by Beijing and the Energy Conservation Design Standards for Passive Ultra-Low Energy Residential Buildings in Shandong Province, which have been implemented since 2016. At present, at least 15 provinces (autonomous regions) and 17 cities have formulated technical guidelines, design standards, development plans and incentive policies for passive ultra-low energy buildings.

Policy Framework

To address both social and environmental challenges, the Sustainable Development Goals (SDGs) and carbon-neutral development pledges by states place new demands on transformative innovation. This is mostly because they are oriented towards overarching goals rather than precise and easy to measure indicators. Sustainable and carbon-neutral development require lifestyle changes and transformative changes in multiple social sectors. In policy practice, therefore, local and national governments need to apply a more holistic approach to facilitate networking and interaction between government, market and society, and to establish a fair and transparent policy framework. For example, in the energy production and consumption chain, energy consumers in the traditional sense, such as urban residents, can become producers and consumers ('prosumers') by installing rooftop PV equipment. In this context, the development and shaping of the market is no longer a unidirectional process in which energy suppliers are the main producers, but a process in which more and more users are involved. Here, policy practice becomes a collective process of experimentation and learning. This also requires a policy framework that provides a certain degree of openness and flexibility for future developments. How to achieve a balance between normativity and flexibility is a key issue for policy makers in this area.

2.5 Case study 5: Energy Transition Lab Reallabore

The 'Energy Transition Lab Real-World Laboratories' ('Reallabore') is a cross-cutting project on energy transition led and funded by the German Federal Ministry of Economics. Its main goal is to test different energy technologies and their interactions in a real environment in order to accelerate the translation of innovation into practice. Innovative technologies, products, services or methods can be tested and applied under real conditions that are partially compatible with the

existing legal and regulatory framework. The results of the laboratory, although a product of specific time and space conditions, can provide a concrete empirical basis for further development of the legal framework. There are many aspects of regulatory uncertainty in the field of innovation. Moreover, rapid digital development has made many regulations developed decades ago no longer relevant. The Lab project can help develop and optimize a more rational legal framework without rejecting meaningful and necessary standards, and facilitate the matching of the pace of regulatory improvement to the high speed of digital development. Since 2018, when the German Federal Ministry of Economics announced the implementation of the Energy Transition Lab program and published the related strategy document, several batches of high-quality projects have been funded.

The North German Energy Transition Lab (Norddeutsches Reallabor) project, which started on April 14 of 2021, will use the next five years to conduct research on the role that hydrogen plays in the sectors of industry, transportation and heating. The Lab builds on the North German Energy Transition 4.0 project, one of the five demonstration regions of the SINTEG (Smart Energy Showcase - Digital Agenda for Energy Transition) program funded by the German Federal Ministry of Economic Affairs and Energy. The project is led by the Hamburg University of Applied Sciences with partners in the four regions of Hamburg, Schleswig-Holstein and Mecklenburg-Vorpommern from different sectors such as business, science and politics and covers the entire energy value chain - from power generation to transport and storage to energy consumption.

The project consists of two main focuses of work: Firstly, sectoral coupling with a focus on hydrogen, which can be used not only as an alternative fuel for buses and private cars, but also as an alternative to natural gas as an energy source for sectors such as industry and heating, reducing CO_2 emissions from industrial production processes. Secondly, district heating solutions, where the project hopes to use heat from waste incineration and industrial production, feeding it into existing district heating networks to promote thermal energy turnover.

In the North German Energy Lab, experts will venture new ideas, test new technologies and conduct research in the context of real market conditions, aiming to apply the findings to other regions and boosting regional economies. The North German Energy Transition Lab project is funded by 52.3 million euros from the German Federal Ministry of Economics, and the work is expected to save more than 500,000 tons of CO^2 emissions per year.

3.Conclusion

With sustainable development and carbon neutral development becoming the consensus of the international community, there are already many technologies and application practices that can provide assistance to achieve these goals. As the main battleground for energy transition and climate protection, cities need to promote the related work systematically and at scale as soon as possible while maintaining continuous innovation. Of the four dimensions presented in

this paper, the first three "vision, roadmap, and implementation measures" are directly related to the goals, pathways, and piloting of innovation at city and local levels, while the fourth policy framework dimension requires more communication and collaboration at the local, national, and even international levels. In particular, in constructing visionary goals, cities can set reasonable goals within the framework of UN sustainable development and international climate action, taking into account their own development and the requirements set by higher-level steering governments and units. In the process of pathway mapping, it is particularly important for the city's decision makers to make comprehensive coordination efforts and to incorporate a wide range of opinions and suggestions. Measures such as strengthening stakeholder communication and increasing public participation can better balance the needs of all parties and lay a good foundation for the smooth implementation of the roadmap. Finally, the adoption or establishment of standardized management methods and clear quality assurance processes, especially the pilot application of innovative ideas, will help to complete projects efficiently. On this basis, professional communication and publicity work will enable the pilot projects to play a better demonstration and leading role, which will in turn promote the formation of new models and new business models that can be replicated and scaled up.

The challenges that climate change poses to human society are of high concern. Cities, localities and countries, governments, markets and societies need to work together and respond positively to promote the dissemination, practice and promotion of new development paradigms led by sustainable goals and carbon neutrality goals.

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Danish experience and innovation in carbon neutrality

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Abstract

The rising worldwide demand for energy is one of the world's major concerns today in terms of climate change. This emphasizes the importance of finding sustainable alternatives to fossil fuels, and there is growing interest in Danish carbon-neutral technology solutions. Denmark is in a unique position to assist other nations across the world in making a more rapid transition to a green economy.

Denmark has been dedicated to becoming carbon neutral since the 1970s. Recently the Danish Ministry of Climate, Energy and Utilities publicly released the Climate Act , the purpose is to reduce the total greenhouse gas emission by 70% of the amount in 1990. Furthermore, the Danish government is aiming for achieving carbon neutrality by 2050 at the latest time frame, as they take the Paris Agreement target of limiting the global temperature rise to 1.5 degrees Celsius into consideration.

The article illustrates the current green transition trend in Denmark and the Danish dedication in being more carbon-neutral. Mainly the article shares case studies in: 1) Sino-Danish collaboration in research of renewable energy and energy saving 2) governmental initiatives of pushing green agenda 3) commercial cases in green building to reach carbon neutral.

Keywords : Carbon Neutrality; Green Building; Energy Saving ;Sustainable; Sustainability; Neutrality; SDG; Sustainable Development Goals; Climate Change; Denmark

1.Overview of Denmark's Integrated National Energy and Climate Plan

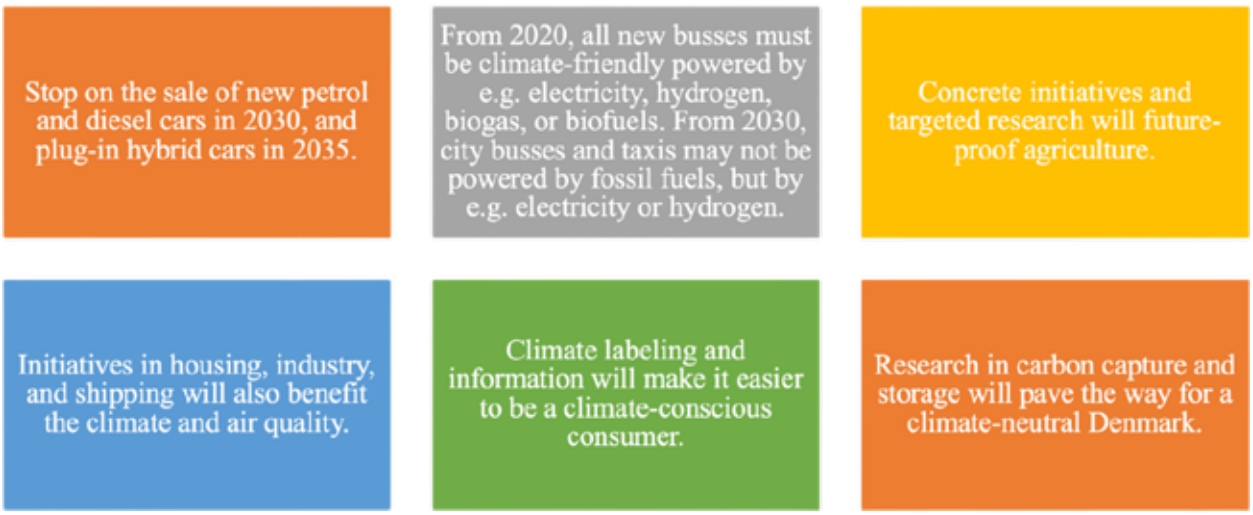
1.1 Danish Connections with Global Climate Plan

With the rising awareness of global climate change, an increasing number of countries actively participate in the reform of their energy usage and storage in order to create a more sustainable future. According to the report published by International Energy Agency (IEA), it advocates for countries around the world to reach the goal of a net-zero energy system with zero carbon dioxide emissions by 2050, while guaranteeing stable and affordable energy sources, as well as thriving economic growth. Priority action strategic framework is made with detailed plans to support the boosting development in sustainability

(Appendix A).

Denmark is one of the IEA (International Energy Association) country members. Moreover, according to *Denmark's Draft Integrated National Energy and Climate Plan* under the Regulation of the European Parliament and of the Council on the Governance of the Energy Union and Climate Action submitted to the European Commission in 2018, Denmark has already made continuous and effective efforts in reducing greenhouse gas emission and increasing renewable energy usage since early 1990s. Also, Denmark prioritizes = carbon neutrality.

In accordance with the Climate Convention which set the goal of reducing greenhouse gas emissions in the first decade from 1990, Denmark had successfully achieved a 5% reduction in CO_2 emissions in 2000 compared to the 1900 adjusted level in the Land Use, Land Use Change and Forestry (LULUCF) sector (Figure 1.1). The first table shown below illustrates the LULUCF greenhouse gas emissions and removals from 1990 to 2018, as well as the expectation of future data from now to 2040. Except for land use, land-use change, and forestry emissions, Denmark also made incredible progress in controlling industrial greenhouse gas emissions and removals between 2008 and 2012, with a 21% drop in total, while the European Union (EU) committed to reaching the target of 8% on average (Figure 1.2). In addition, the share of renewable sources in the gross final consumption of energy in Denmark has continuously increased over the last decades, reaching the point of approximately 36% in the year 2020 (Figure 1.3). Overall, Denmark has become a world-leading country in carbon-neutrality by making progress in diverse fields from a whole perspective based on their accumulated experience over the past few decades.



1.2 Danish Carbon Neutrality Action Strategy

The globe is facing a climate crisis. We use up more of the planet's resources and emit more pollution than it can handle. These actions have ramifications, especially in urban centres. The previous four years have been the hottest on record for the planet. The world's seas are rising at an unprecedented rate, and the amount of sea ice left in the Arctic has reached a new low.

Frameworks beyond 2020

Denmark has established its own framework for progress in carbon-neutrality beyond 2020 in order to keep up with the IEA's global "net-zero" objective. Some of Denmark's carbon neutrality targets beyond 2020 are as follows:

Referring to the effort on being carbon-neutral, Denmark will work toward its domestic targets of reaching a share of around 55% renewable energy by 2030, phasing out coal before 2030, lower emissions from industry and housing, and so on, in order to reach the goal of a climate-neutral Denmark by 2050.

2.Case Studies

Beyond Denmark's boundaries, Danish consumption and activities have an influence on greenhouse gas emissions. Danes buy products made in other nations. As a result, the average climatic footprint of Danes is higher than that of the rest of the country. As a result, Danish businesses' attempts to incorporate sustainability into their value chains and export green solutions are critical components of Denmark's entire worldwide strategy. The government is also collaborating with a number of rising economies to reduce global emissions through bilateral Strategic Sector Cooperation.

Since Denmark has experience in pushing

green transition forward and also to be dedicated to being one of the pioneers in carbon neutrality journal, it is also critical to find practical aspects that can be localized in cities around the world.

The following case studies illustrate the carbon neutrality experience in collaboration process, sustainability awareness platform creation and concrete green process development.

2.1 Governmental Initiatives of Carbon Neutrality

Nordic Sustainable Cities

Millions of people across the world are affected by the increasing rate of urbanization, which poses health, safety, and environmental problems. It also creates a rising worldwide need for urban environmental solutions.

Referring to the UN report *World Urbanization Prospects*, by 2050, urban conurbations are anticipated to house 68 percent of the world's population. The UN Agenda 2030 recognizes cities' critical role in promoting sustainable development and emphasizes the necessity of making cities more inclusive, safe, resilient, and sustainable. Approximately 85 percent of the Nordic population lives in cities.

In order to create the synergy between Nordic and Chinese path of being sustainable and carbon-neutral, a flagship project called Nordic Sustainable Cities was initiated by Nordic Innovation, with the joint effort among five Nordic official governmental entities: Innovation Centre Denmark, Business Finland, Business Sweden, Innovation Norway and Icelandic Embassy. The initiative is to promote Nordic sustainable solutions to the Chinese market to solve the current demanding sustainable problems, which intends to create concrete business opportunities in carbon-neutral related industries. The initiative also has relevance to other cooperative arrangements and to how cities can move forward with zero carbon emissions.

Nordic Sustainable Cities is one of six flagship initiatives within Nordic Solutions to Global Challenges, a joint initiative of the five Nordic prime ministers to share Nordic expertise and experience to help the UN Sustainable Development Goals be met. The Nordic Council of Ministers is in charge of coordinating the project. The Nordic Low Carbon City takes use of urban inhabitants' proximity by bringing together efforts that cut emissions without stifling economic growth.

"Nordic Solutions to Global Challenges is a joint initiative by the Prime ministers of the Nordic countries. We want to invite the world to share Nordic knowledge and experiences of six priority flagship projects. These Nordic solutions will be effective tools in our common work to reach the United Nations Sustainability Goals before the year 2030. "
---Nordic Council of Ministers

Buildings, transportation, and energy are the focus of Nordic cities' low-carbon initiatives. Many structures are constructed to surpass national construction codes, multimodal transportation networks encourage group travel, and renewable energy is progressively incorporated into the energy supply for industry, residential areas, and public transportation. Transitioning a city's activities from a conventional to a circular economy mod-

"Nordic Solutions to Global Challenges is a joint initiative by the Prime ministers of the Nordic countries. We want to invite the world to share Nordic knowledge and experiences of six priority flagship projects. These Nordic solutions will be effective tools in our common work to reach the United Nations Sustainability Goals before the year 2030. "

Nordic Council of Ministers

el necessitates systematic transformation and an inclusive strategy that encompasses more than just one firm or organization. City governments, businesses, and individuals all throughout the Nordic area are working on new methods to boost the potential of products and services. A major premise of circular economy efforts is to design waste out. Nordic communities are increasingly trying to benefit from resource efficiency, according to businesses. The materials used to create new structures, the recycling of inhabitants' trash, and the energy extracted from sewage networks all help to improve the efficiency of current urban systems.

2.2 Triple-helix Cooperation in Carbon Neutrality

It is critical to involve higher education entities to push carbon neutrality forward, together with the support of the government and also the validation of business corporations. A unique yet innovative project called Aurora is a perfect case of illustrating the triple helix model of how joint effort is distributed among three parties with academia, industry and government, to foster economic and social development.

Aurora and the LOOP of Aurora

I.Solar Decathlon China and Aurora

Aurora is the entry of Team Aurora jointly built by the Technical University of Denmark (DTU) and Soochow University (SUDA) for Solar Decathlon China 2021 (SDC) competition.

SDC is the derivative of SD (Solar Decathlon), which is an international collegiate architectural competition founded by the United States Department of Energy, aiming to inspire thousands of college student teams to design, build and operate innovative, sustainable, resilient, and affordable solar-powered houses with high performance and low carbon footprint. Solar Decathlon is organized in six continents at present, and Solar Decathlon China 2021 (SDC) is the one Aurora participates in. The SDC2021 will take place in the fall of 2021 in Zhangjiakou in China with three main challenges – sustainable development, smart connection, and human health.

Aurora is one of the 15 houses participating in SDC. It is designed by DTU and executed by SUDA. It is a house dwelling not only magnificent and innovative designs, but also carbon-neutral and sustainable ideas. Aurora house invites residents to use body and mind every day, in a positive dialogue between human and the house. Also since Aurora is located in Zhangjiakou, which is officially assigned for Winter Olympics 2022's residential purposes, it will be a perfect demonstration to the world how to pursue carbon-neutrality in residential houses.

II.How Aurora approaches carbon neutrality from a technical perspective

The house needs to provide its inhabitants with safety, social life/private life, creative activities, and fit life within the privacy of the home. The Aurora house allows public and private action spaces to interact in a flexible way, as it is designed with public, semi-public, and private spaces, which could be easily adaptable through minimal physical changes. Moreover, it is a project combining both Scandinavian and Chinese architectural and cul-

tural elements based on the target of sustainability. Wood, natural materials, natural light, and clean lines are all hallmarks of Scandinavian design. Meanwhile, bamboo has a lengthy history in China on the opposite side of the world, which could also be identified as a type of sustainable, renewable, fast-growing, cost-effective, and long-lasting material. Bamboo is utilized as one of the major materials in the Aurora design, both for structural components like beams and columns, as well as external cladding and interior design. Aurora is attempting to replicate the flexibility and long-term durability of Scandinavian houses with the 1.5 house idea. The 1.5 home has a three-bedroom main house and a smaller second house (0.5 home) that may be used as a studio, workplace, or fitness centre, among other things. Residents may use this area in a variety of ways depending on their requirements, allowing this home to fulfill a variety of roles.

Carbon-neutral design could be found in various aspects of Aurora house. One highlight could be its solar roof, which acts as a key component of the overall design. It not only supplies electricity but also adds to the overall aesthetic of the surroundings and building. It has space for solar panels and allows for the presentation of a zero-energy home.

The importance of ventilation in maintaining appropriate indoor air quality cannot be overstated. The contemporary building environment employs an effective ventilation strategy to aid in providing a pleasant thermal indoor temperature in an energy-efficient manner, in order to fulfill the rising comfort demand as well as to preserve the health and well-being of inhabitants. The whole system has the potential to help reduce CO_2 emissions from coal and biofuel power plants.

III.How Aurora develops carbon neutrality platform for knowledge exchange and localization

Beyond the physical Aurora house, an multidimensional platform could certainly call attention. The LOOP of Aurora stands for the platform established in relation to this project. Aurora is supported by Industry Fund, which is a Danish organization that invests in entrepreneurs, researchers, and businesses relating to society's challenges and benefitting Denmark. Besides, this project is facilitated by Innovation Centre Denmark (ICDK), which is an organization aiming to help Danish research institutions and companies with access to foreign knowledge, networks, technology, capital, and market opportunities. Furthermore, there is a green building alliance related to Aurora, together with companies within the green, smart and health-oriented houses. In

other words, the LOOP of Aurora is a platform that connects universities, governments, and businesses.

There are four main types of activities provided for small and medium enterprises (SMEs): Aurora Roadshow, which is a presentation slot for the webinar with a display booth for the company; Physical Utilization at Aurora, in which the products inside the house will be directly demonstrated to the Chinese audience and relevant groups interested in it; Matchmaking Session where matchmaking between 10 Danish SMEs and Chinese potential consumers, partners and distributors Publicity takes place on social media; and Exhibition. In fact, several presentations, roundtable discussions, workshops, and roadshows has been successfully held since the project began. More exhibitions are planned in the near future after the Aurora house construction and the SDC competition. The LOOP of Aurora has successfully generated the cooperation between nations in the field of carbon-neutrality, which also meets the frameworks for both IEA's "net-zero" goal as well as Danish domestic development plan.

2.3 Carbon Neutrality Implementation in Asia

Not only China is proactively looking for Danish experience implementation in Chinese scenario, other Asian countries i.e. Korea, Singapore and Japan are also seeking sustainable solutions.

The case study that follows is executed by Innovation Centre Denmark Seoul.

2.3.1 Water Treatment & Resource Recovery of Sewage and Sludge in Daegu

Daegu is the fourth largest city in South Korea, with a population of about 2.5 million people. With the goal of becoming a Net Zero city, the city must discover new applications for the sludge collected from Wastewater Treatment Plants and enhance their treatment processes. The project of Water Treatment & Resource Recovery of Sewage and Sludge in Daegu was brought out to promote the city's carbon-neutral plan. Three countries' expert-teams are involved in this project, including, South Korea, Mexico, and Denmark. Similarly to the project of Aurora house, Innovation Centre Denmark (ICDK) based on South Korea is responsible for assisting Danish corporations to put into their innovation and services.

I.SludgeX – Team Denmark

The Daegu Environmental Corporation presented SludgeX with a problem involving sludge management efficiency at their biogas-producing wastewater treatment plants, and tasked SludgeX, along with other teams from around the world participating in the Next Generation Water Action initiative, with finding a solution.

The coagulated organic semi-solids collected as a consequence of processing incoming sewage wastewater for recycling or return to the environment are known as sewage sludge. This sludge isn't simply waste; with the appropriate equipment, it may be a significant resource for renewable energy. The energy is trapped inside the sludge's organic carbon molecules.

These molecules may be broken down and reformed as methane, a very energy-dense fuel that can be utilized to create heat and energy, in a process known as "anaerobic digestion." We'll discover how this process works in the following part, as well as how SludgeX optimizes the system for optimum sustainability and efficiency.

II.Technical Process

Anaerobic digestion is a process in which bacteria eat the organic molecules of sludge in an oxygen-free environment, causing the bacterium's gaseous output to lack oxygen molecules as well, resulting in CH4, or methane, which is mostly made of carbon and hydrogen. Methane is a very efficient fuel that may be utilized for both heating and power generating. WWTPs make use of this process by digesting sludge for biogas generation and using the energy for onsite activities, increasing the facility's sustainability by lowering emissions from processed sludge outside of the treatment plant.

Pyrolysis, another technique of recovering energy from sludge, is used in our unique system. Pyrolysis is not a new technique; there is plenty of study and technology on the subject; however, our system uses pyrolysis in conjunction with anaerobic digestion to maximize the use of energy trapped in the sludge in a unique configuration that maximizes both sludge digestion and pyrolysis. Details have been withheld due to the novelty of the concept, but SludgeX is taking the beginning steps toward patenting this method.

With a reduction in biogas energy usage of about 50%, an increase in biogas output of up to 24%, and cost savings that can pay off the capital investment in as little as four years, the solution can deliver both energy and economic advantages.

This approach has the potential to create considerable monetary value from the enhanced biogas recovered, as well as assisting wastewater treatment facilities in using less outside energy and squandering less energy in the sludge that is transported to thermal power plants, which they pay to burn for them.

When biochar production is scaled up to replace the end destination of thermal power plants, the carbon trapped in the biochar can create a negative carbon footprint, enhancing the sustainability of cities across the world. The value and motivation of sustainability has risen substantially in recent decades, and our approach can help achieve four of the seventeen United Nations Sustainable Development Goals: .SDG 3, SDG 6, SDG 7 and SDG 13.

This is another innovative way to introduce Danish experience to Asian market in carbon neutrality technically and commercially.

2.3.2 Dujiangyan Giant Panda Rehabilitation Medical Treatment and Research Centre, Wolong National Conservation

Velux is one of the leading Danish companies driving sustainability and carbon neutrality in their business genes. The following case of Dujiangyan Giant Panda Rehabilitation Medical Treatment and Research Centre is one perfect example of merging Danish nature-based sustainable solutions into Chinese application. Velux has utilized their windows into the Panda Centre in order to make the

house breathing and energy-saving.

Dujiangyan giant panda rehabilitation medical treatment and research center, Wolong National Conservation is a funded project by the Hong Kong government after the 5.12 Sichuan earthquake in 2008. It is the world's first panda hospital which has functions of giant panda disease treatment, recuperates, disease research, and scientific education. The project has a design concept of achieving the minimum energy consumption during the full life cycle of the architecture. The project has obtained China's three-star green certification of both design and operating.

The design combines panda medical craft with the requirements for eco-environment protection, and generally follows the terrain and western Sichuan "Linpan" pattern. The buildings and the environment are in harmony with each other. And thus the ecological wetland in the Center is protected. The architectural form inspired by the local dwellings tries to fit in with the environment. The project utilizes the proper environmental protection and energy-saving measures and techniques such as the waste bricks in the old buildings, ground source heat pump, rainwater collection, rain penetration through road and pavement, passive ventilation ceiling, and compound insulation of the wall.

According to the corresponding functional requirements, the main buildings and roads are arranged according to the local conditions by using the original homesteads and roads, so as to maintain the original topography, vegetation, wetlands, and water systems to the greatest extent and reduce soil erosion. The green area rate of this project reaches over 80%. All the lanes, sidewalks, and parking lots are paved with water-permeable materials, and the outdoor permeable ground accounts for 82.5% of the total area.

Considering the natural conditions of the site and the local economic level, the appropriate result-oriented low-carbon technologies are employed in the Project, so as to reduce the overall energy consumption of the buildings, and cut down the maintenance cost. The use of technologies to achieve low-carbon and energy-saving goals could be found in two designs, including water resources utilization and soft water collection and reuse These two designs allow the total effective regulation and storage volume reach the point of 3000 m^3, and the utilization rate of non-conventional water source reach 60.3 percent .

The design of the project inherits and improves the ventilation and insulation layer of traditional dwellings, and further reduces the energy consumption of building space by using new materials on the basis of basically retaining the original architectural logic.

On the basis of absorbing traditional architecture wisdom, the project limits the energy consumption zone to a reasonable range by embedding an insulated suspended ceiling. So that we can take advantage of the vertical temperature difference in the air to form natural ventilation.

Through the comprehensive use of a variety of green technologies, the building has achieved energy saving of 60.6%. According to the measurement results, the building energy consumption per unit area is only 48 kwh/(m2·a), which is 36% lower than that of con-

ventional buildings.

2.3.3 Passive House Experience Center at the Sino-German Ecological Par

This is another example of implementation of Danish low-carbon experience into Chinese scenario in green building area. Rockwool is the leading sustainable construction material suppliers, who is originally from Denmark. The facility is located in the core area of the Qingdao Sino-German Ecological Park, the Passive House Experience Center (hereinafter referred to as the "Experience Center") is a multi-purpose building that integrates a number of functions related to passive ultra-low energy consumption. These include green construction technology Research and Development, the experience center, an exhibition area, conference rooms, residential areas, and others. With a total area of nearly 14,000 square meters, the Experience Center has five floors above ground, one floor semi-underground and one floor underground. It is the first high-standard passive house project in Asia, and is a result of a technical cooperation between China and Germany. The project uses a green, low-carbon design concept that matches the properties of ROCKWOOL stone wool – the material is used in the building's external wall insulation.

Passive House is a new type of building, established on the basis of low-energy buildings. It is kept warm primarily through heat preservation and airtightness, rather than using a conventional heating system. The Experience Center's insulation layer uses ROCKWOOL stone wool with a thickness of 150 mm to 250 mm. This material has been highly praised by the owners and designers of the project thanks to its excellent thermal insulation performance and outstanding durability. These ensure that the project will always maintain its design performance standards and functions during later use.

Passive House maintains an indoor temperature of 18°C to 26°C throughout the year, with no need for air conditioning in summer or heating in winter, effectively improving indoor comfort levels. The Experience Center achieves incredible energy savings thanks to its high-quality thermal insulation materials and passive building design. It is estimated that it can save 1.3 million kWh of energy every year and reducing 664 tons of carbon emissions. It has passed Passive House Certification at the Passive House Institute (PHI) in Germany and has been awarded three-star Green Building certification in China. The Experience Center is now the single largest passive building in Asia, and features the most complex functions passive house in the world. It was selected as the 2017 Science and Technology Project by China's Ministry of Housing and Urban-Rural Development. ROCKWOOL has participated in the Experience Center construction since the early stages of the project. The outstanding building insulation performance brought by ROCKWOOL stone wool has become the key to the success for the Passive House project.

2.4 Innovation Research in Carbon Neutrality

Beyond the fact that we are contributing to a greener, more sustainable, and equitable world, it benefits Denmark to enhance our worldwide efforts for green transition. Green exports, growth, and employment in Denmark

Figure 2.4.1 Solar Farm and Wind Farm in Denmark

are all aided by the expansion of Danish green solutions. Our commitment to global climate action can help us acquire expertise, new technology, solutions, and investments, which will assist Denmark's own green transition, future-proof our economic positions, and help us reach our ambitious climate targets.

Seeking and validating the process of transition from traditional fuel resource into renewable energies is also a very effective way to approach carbon neutrality. By collaborating researchers both from China and Denmark can be a positive approach to figure out best practice to adapt to renewable energy. The following cases are currently ongoing, and both are supported by Innovation Fund Denmark.

2.5 HEAT4RES - Using Flexible District Heating with Heat Pumps for Integrate Electricity Heat Dispatch with Renewables

The project "Using Flexible District Heating with Heat Pumps for Integrated Electricity and Heat Dispatch with Renewables" (HEAT4RES) was launched in 2019. District heating heats two-thirds of all Danish households. Combines heat and power (CHP) plants, which mostly burn coal and gas, provide 40 percent of the heat. Coal and gas-fired CHP facilities must be phased out in order to meet the national objective of achieving a fossil-fuel-free power and heat supply by 2035. The HEAT4RES project aims to create solutions to enable the cost-effective and secure operation of energy systems with high renewable energy penetration by implementing heat pumps in the district heating system with existing electric boilers and heat storage. The Center for Electric Power and Energy, DTU Elektro and Vestas are organizations from Denmark, who will cooperate with their Chinese partners Tsinghua University, North China Electric Power University, Guodian New Energy Technology Research Center, and Yantai Longyuan Power Technology Ltd Co to optimize the integrated electricity and heating system. If the initiative is successful, it will save Danish power customers millions of kroner. Besides, it will also provide universal answers for future green electricity and heat delivery. Energy technology suppliers and utility corporations will ultimately put the project's findings into practice. The value produced will benefit society, energy technology providers, heat suppliers, and end-users.

2.6 IECC - Integrated Energy Conversion and Control for Smart and Efficient Electrolysis System

Denmark aspires to be fossil-fuel-free by 2050. As a result, alternate energy storage for the electrical system and energy transportation is crucial. At the same time, in 2016 and 2017, China stopped using 100 billion kWh generated from renewable energy sources. This is three times the total yearly electricity usage of Denmark. The Integrated Conversion and Control for Smart and Efficient Electrolysis System – IECC becomes the project to develop an affordable and efficient energy-to gas/hydrogen system. The potential solutions that researchers try to figure out through this project include reaching high efficiency by new configuration with fraction power processing, using smart electrolysis to reach flexibility, and reduce cost by using ac filtering. For Denmark, this project was carried out through the collaboration between Danish and Chinese partners in electrolysis in late 2019, and it is expected

to end in 2022(1). The cooperation organizations within this project include DTU, NPC Tec, GreenHydrogen from Denmark and the National Institute of Clean and Low Carbon Energy (NICE); Sichuan Energy Internet Research Institute, Tsinghua University; China University of Mining and Technology (Beijing); Zhentai Energy Technology co. ltd; Beijing Huadian Tianren Electric Power Control Technology co. ltd; State Grid Sichuan Electric Power Company from China. The innovations and patents submitted by the partners will be used in commercialization, and future research and development.

3.Conclusion

In order to implement Danish experience into Chinese scenario, some efforts are required:

1. Both Danish and Chinese government need to make joint effort on localization project by providing policy and financial support to explore the possibilities
2. More platforms and projects need to be created to facilitate knowledge exchange between Denmark and China on academic perspective
3. More promotion and branding activities need to be executed to the public
4. Flexibility and alternation need to be applied into Chinese cases if needed, direct danish implementation in carbon neutrality is not recommended; pilot study and demonstration is highly encouraged
5. The collaboration between China and Denmark need to be pushed more in order to maximize and optimize the green transition towards carbon neutrality.

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According to the most recent analysis in the "***Global Financial Stability Report***", released by the IMF, the investment fund sector over a scale of 50 trillion US dollars (especially the sustainable investment fund sector) can be an important driver of the global transition to a green economy and help the global steer clear of some of the most dangerous consequences engendered by climate change. At the 11th session of the World Urban Forum (WUF11) in 2022, the dialogue for the future city's economy and finance was set as one of the six theme dialogues, indicating that those countries and cities must provide financial support and relief to a range of targeted entrepreneurs, to restore and maintain the inclusive and achieving sustainable growth of marching on the road. The carbon neutrality initiative involves the transformation of the industrial structure, economic structure, and financial system. It will bring about a tremendous gap of capital but also a reservoir of profit whose value is severely undervalued. We need financial instruments to direct the flow of capital and build a renewable green business cycle. Two articles in this chapter, which respectively themed on green commercial banks and building financial data factor market for carbon neutrality, offer inspirations in green finance transformation and innovation, carbon credits and carbon incentive systems under the perspective of public-private partnership.

CHAPTER FOUR:

GREEN FINANCE INNOVATIONS IN CITIES

Green bank transformation case for carbon neutrality

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1.Why Greening Commercial Banks?

To achieve global climate targets and respond to the policy packages needed for cities to reach carbon neutrality, tremendous financing is required that cannot be fulfilled by the public sector alone. Private sector financing is crucial to a successful green transition. The financial sector, and commercial banks in particular, therefore have an important role to play - not only through providing sustainable financial products and services, but also by influencing other sectors in a variety of ways including sustainable investment trends and innovations in operations.

This need also brings great investment opportunities. The International Finance Corporation's (IFC) research estimates that cities in emerging markets alone have the potential to attract more than USD 29 trillion in climate-related investments by 2030 (IFC 2018). Key sectors include green buildings, low-carbon transportation, climate-smart urban water and waste management infrastructure, and renewable energy. Today, banks in Asia have an estimated combined green portfolio of over $200 billion - generating the potential to reduce up to 200 million tons of Green House Gas emissions annually. That's the equivalent to closing 35 1000 mw coal-fired power plants a year.

2.What is a Green Commercial Bank? How Does It Work?

Green commercial banks means a few things, and greening the portfolio is only part of the picture. To achieve a green transformation, commercial banks also need to innovate and mainstream more focused financial products to unlock potential markets and meet their climate commitments; develop mid to long-term strategic planning on sustainability; enhance bank-wide knowledge and capacity in green finance; and so on.

Responding to the growing demand from financial sector clients and international partners for a more standardized approach to ensure the credibility of green banking, IFC has recently launched the Alliance for Green Commercial Banks. This new global initiative will bring together financial institutions, research bodies, and technology providers to accelerate the adoption of green banking practices and increase financing available for

climate investments.

Leveraging IFC's extensive global experience and local market knowledge in climate finance and sustainability risk management, the Alliance has proposed aspirational goals and the following five pillars for commercial banks' green transformation. The purpose of this five-pillar framework is to guide banks' strategic planning, while also allowing flexibility in exploring differentiated and distinctive green development paths. Below is a high-level illustration of how it works and some real-world examples:

1. **Green Portfolio:** Help greening loan portfolios, with a goal to mainstream green finance and reduce financing to emission-intensive industries. For example, the Industrial Bank - the green finance lead in China - has expanded its green assets to account for 15% of total assets (well above the country's banking sector average of 10%). Its total outstanding green finance volume reached USD 177.8 billion as of 2020.

2. **Green New Business:** Encourage designing new products and services to grow the green business and serve the green market. For instance, Ukrgasbank - IFC's "green bank" sample in Ukraine - has disbursed over 400 loans for mid to large-scale green projects and provided more than USD 800 million in green loans since 2016. Bank OCBC NISP - a pioneer in the Indonesia green bond market - issued the country's first-ever green bond by a commercial lender (IFC investment of USD 150 million). The bond aims to fund environmentally friendly projects and help the nation mitigate climate impacts.

3. **Strategic Commitment**: Putting in place mid to long-term strategic planning on sustainability and attaching the importance of improving internal capacity on green finance. Namely, Hongkong and Shanghai Banking Corporation (HSBC) announced an ambitious plan to prioritize financing and investment that support the transition to a net-zero global economy in 2020. The plan includes financial support, climate solution and innovation support, and net-zero bank commitment. In 2015, Citibank announced its Sustainable Progress Strategy, which organized the bank's work into three pillars: Environmental Finance, Environmental and Social Risk Management, and Operations and Supply Chain.

4. **Carbon Neutral:** Support the decarbonization of operations and/or portfolio to achieve carbon-neutral. For example, Deutsche Bank has set the goal of reducing its carbon footprint and has achieved carbon neutrality with its business operations in 2013. Last year, Standard Chartered Bank announced its goal to achieve net-zero carbon emissions from its operations by 2030. BlackRock - the world's largest asset manager - has started to provide publicly available data on the carbon footprint of its mutual funds on its website since the end of 2020.

5. **Environmental, Social, and Climate Risk Management:** Help to manage exposure to climate risks and adhere to international good practices on managing environmental and social risk and performance in lending and investment. For instance, as a leading asset management company in the area of ESG management, UBS has been continuously disclosing its ESG reports and announced its long-term development goals in targeted years. Since 2017, Vanguard has been asking its investee companies to disclose climate-related risks. S & P Global has included climate risk as a determinant for its ratings.

We believe that a financial institution needs to have indicative results or clear action plans to address at least three of these pillars, if not all of them, in order to achieve a green transformation.

Below are three detailed real-world cases looking at how large universal banks, as well as small and medium-sized commercial banks, are progressing on their green paths. While not all of them are undertaking the transformation through the Alliance's framework, it is worth noting that their plans share a high level of synergy.

3.Case Studies

Nordea Bank, Nordic Region:

Nordea is the largest bank in Northern Europe with a total of EUR 354 billion assets under management and EUR 8,466 million of operating income. The bank serves customers across 22 countries with four service areas - personal banking, business banking, large corporations and institutions, and asset and wealth management.

Over the last few years, Nordea has received an increasing amount of inquiries on sustainable financing from its corporate, institutional, and household customers. In response, the bank has taken the initiative to offer several products and financing solutions to support clients' needs in addressing climate change. Nordea has also recently announced plans to reduce its holdings of oil and gas stocks, namely, in Finland, it will restrict more than 200 of its funds that manage a combined 120 billion euros (USD 143 billion) from holding oil and gas stocks. To avoid elimination, an energy provider needs to provide evidence indicating that it is on a green transition path. Shares of BP, Royal Dutch Shell, Equinor, and Total have already been sold due to failure in meeting the requirements (Bloomberg Green 2021).

To illustrate Nordea Bank's best practices, below are some selected examples given from the bank's Sustainability Report 2020:

Pillar 1 - Green Portfolio

Nordea offers green corporate loans to Small and Medium Entreprises (SMEs) and large corporate customers based on 6 different green asset categories (renewable energy, energy efficiency, green buildings, pollution preven-

Graph 1: Nordea's green transformation milestones in FY2020 and the Sustainable Choice Symbol

tion and control, clean transportation, and sustainable management of living natural resources) that give eligibility for green loans. After third-party verification, the loans are included in a green bond asset portfolio and eligible for financing through one the Nordea's two green bonds, with a total volume of EUR 1,250 million. In addition to Nordea's green bond, the bank also helps its clients to issue green, social, and sustainability bonds.

Pillar 2 - Green New Business

In 2019, Nordea started providing sustainability-linked loans, which essentially can be any type of loan instrument, but with sustainability performance included in the loan documentation with clear annual targets that the borrower must meet. In addition, Nordea also provides green mortgages, unsecured loans targeting energy-efficiency investments for buildings, green car loans, and green car leasing. To help customers more easily identify sustainable finance products, Nordea also designed a new symbol "Sustainable Choice" to highlight its sustainability offerings.

Pillar 3 - Strategic Commitment

In 2020, Nordea set its mid to long-term targets and plans on enhancing sustainability under four strategic areas - financial strength, climate action, social responsibility, as well as governance and culture. Examples of the targets are given as follow:

1. Financial Strength - Risk management framework for ESG risks in place by 2023; risk assessments in place for the sectors and customers most vulnerable to climate risks by 2023.

2. Climate Action - 25% of gross inflow for savings in sustainable products by 2023; Total carbon reduction from internal operations reduce by 30% compared to that of 2019 by 2023 and reduce more than half by 2030.

3. Social Responsibility - 100% of new suppliers screened for sustainable issues by 2023.

4. Governance and Culture - Sustainable banking implemented as part of Nordea's culture with sustainability targets integrated into people processes, including employee branding and benefit programs by 2023.

Pillar 4 - Carbon Neutral

Nordea aims to reach net-zero by 2050 at the latest and reduce carbon emissions from its lending and investment portfolios by between 40% and 50% by 2030. To achieve these goals, the bank is not only working on reaching carbon neutral downstream, in operations, but also upstream by making climate action one of the strategic focus areas of its sourcing practices. In 2020, Nordea launched various initiatives to minimize bank-wide resource consumption and further embed the circular economy mindset into their business. For instance, in Denmark, Nordea ran a project on refurbishing used IT accessories, in particular headsets, keyboards, and mice. The bank also further integrated climate considerations into its supplier selection process. For selected sectors, Nordea now adds climate science-based questions in its request for tenders to ensure that key suppliers are on a path towards decarbonization as well.

Pillar 5 - Environmental, Social, and Climate Risk Management

As part of Nordea's decision to strengthen sustainability in its business strategy and to ensure oversight of the four strategic areas,

Use of Proceeds	Physical location	Amount financed with proceeds from the bond (NGN)	Date of proceeds allocation	Impact Indicators
Project A: Flood Defence	Victoria Island, Lagos	**12,845,114,325.79**	31/05/2019	• Area resilient against flooding: 900 hectares • Total number of people benefitting from improved resilience against flooding: 400,000
Project B: Solar Energy	Lagos Metropolitan area including - Ojo, Magodo, Ikeja, Ikoyi, Ajah	**1,674,600,042.00**	31/12/2019	• Renewable energy installed capacity: 13.39MW • Renewable energy generation: 22,286 MWh/y • GHG emission reductions: 10,631 tCO2eq/y
Project C: Solar Energy	Enugu, Jos, Port Harcourt, Lagos and Abuja	**103,722,982.85**	31/12/2019	• Renewable energy installed capacity: 0.92MW • Renewable energy generation: 1,531 MWh/y • GHG emission reductions: 730 tCO2eq/y
Project D: Agriculture (Water management)	N/A	**N/A**	N/A	• N/A

Chart 1: Green projects financed by Access Bank in 2019

the bank has established a new Sustainability and Ethics Committee (SEC) in December 2020. SEC will have a stronger and more focused mandate to facilitate the cross-cutting integration of sustainability and to support the adoption of ESG factors in risk management. Furthermore, an implementation structure with five tracks - offering and risk management; competence, education, and awareness; narrative, brand, and communication; people and culture; internal carbon reduction plan - has been developed and will ensure that sustainability is integrated into all business areas and group functions. Progress of the tracks will be monitored by the SEC.

4.Access Bank Public limited company, Nigeria

Access Bank is a Nigerian commercial bank with a net profit of NGN 210 billion in 2019. After going through a merger with Diamond Bank Plc in March 2019, the combined entity became the largest bank in Nigeria by the number of customers and total assets. Access's core business offerings include the provision of money market products and services, retail banking, granting of loans and advances, equipment leasing, corporate finance, and foreign exchange operations.

On the sustainability front, Access is the first Nigerian bank to adopt the Equator Principles - a risk management framework to help

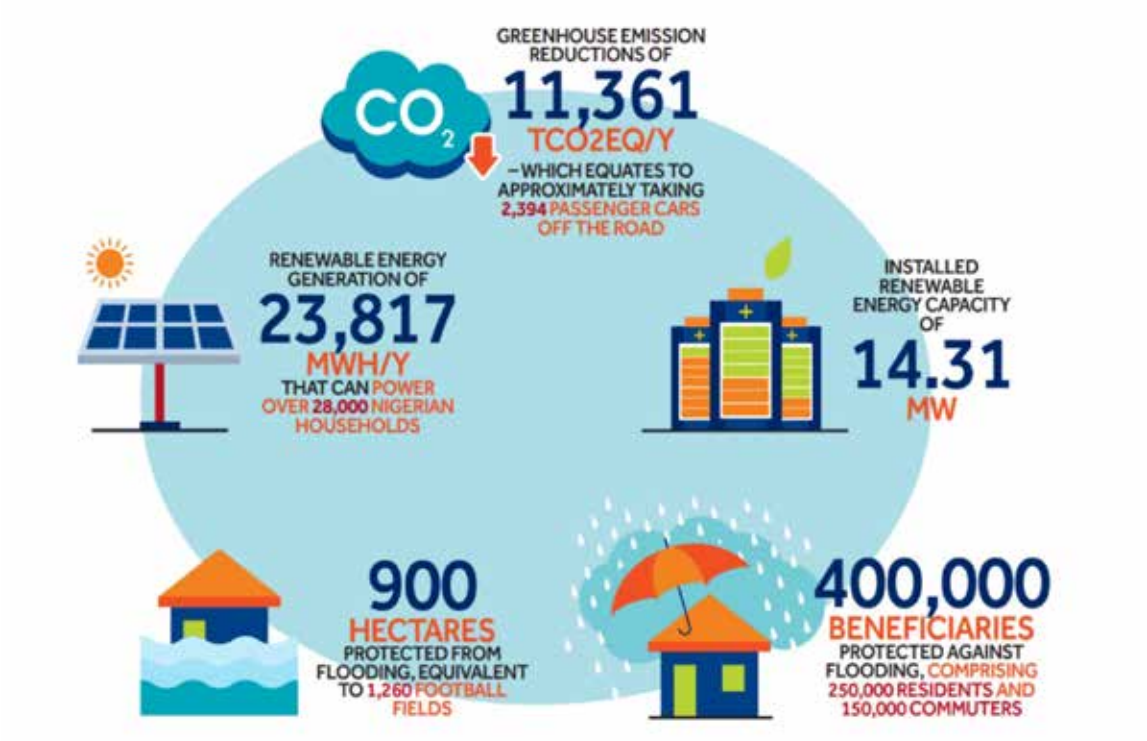
financial institutions to determine, assess, and manage environmental and social risk in projects. It has also been producing standalone sustainability reports since 2010, each year improving the accountability and transparency of relevant data. To have a closer look at Access's efforts towards a green transition, here are a selection of details from its Sustainability Report 2019.

Pillar 1 - Green Portfolio:

As part of its standard credit and risk procedures, Access Bank conducts environmental and social impact assessments on loan projects based on a series of sustainability-related indicators. The assessment also takes into consideration the borrower's overall capacity to manage the impacts. Access also provides green loan funding through its green bond scheme. The chart below illustrates the projects that have successfully received funding and the sustainable impacts generated.

Pillar 2 - Green New Business:

Recognizing the growing interest from environmentally-conscious customers in sustain-



Graph 2: Annual sustainable impacts from green projects financed by Access Bank in 2019

able financing solutions, Access Bank rolled out the Green Bond Market Development Programme in partnership with FMDQ Securities Exchange, Climate Bonds Initiative (CBI), and the Nigerian Securities and Exchange Commission in 2018. Through collaborative efforts, in 2019, Access launched the first CBI-certified corporate green bond in Africa, which was also the first green bond in Nigeria to be cross-listed on the Nigerian and Luxembourg Stock Exchanges. So far, a total amount of NGN 14.623 billion has been allocated to the three green projects demonstrated in Chart 2 above. The collective annual impacts from these projects are as disclosed below.

Pillar 4 - Carbon Neutral:

In its continuous efforts to facilitate a green transformation, Access Bank has been undertaking initiatives to enhance energy efficiency and reduce direct carbon emissions from its business operations. Examples include the 'Employee Commuting Program' which provides shared mobility among colleagues to reduce emissions generated from every transportation, and the 'Paper to Pencil initiative' which collects used calendars, agenda books, and notepads from Access Bank and Diamond Bank and recycles them into pencils for schools in local communities.

Pillar 5 - Environmental, Social, and Climate Risk Management:

In 2019, the Access Group Board has also announced its governance oversight for sustainability management through establishing a Sustainability Committee. The Committee is responsible for overseeing and reporting on the delivery of the Bank's sustainable business strategies, and guide implementations to ensure the achievement of Access' sustainability ambitions in each of the strategic priorities.

3.Ma'anshan Rural Commercial Bank (MRCB), China:

With government supervision and compliance requirements continuing to upscale and business growth rate slowing down, many small and medium-sized banks in China are actively taking approaches to upgrade their risk management system and enhance competitiveness in the market. Under such context, MRCB, a prefecture-level rural commercial bank with a total asset of CNY 51.8 billion, has set out a strategic transformation target to become "the first green commercial bank in China with sustainable finance as its main service" by 2025.

In December 2017, MRCB and IFC signed a cooperation agreement, which would leverage IFC's expertise and substantial experience in climate change to help MRCB work on a holistic transformation and reach the bank's sustainability goals. Specifically, MRCB aimed to increase the ratio of green credit and loans to 60%, that of green financial products to 70%, the number of employees with green certificates to 80%, as well as to achieve carbon neutrality for bank-wide operations and receive green building certificates for all bank-owned buildings.

Through comprehensive evaluation and consultation, IFC helped MRCB to adopt the

Graph 3: Innovative use cases for green financing to smallholders and SMEs

five-pillar approach (mentioned in the previous section) with specific actions. The transformation project was designed to carry out in 4 phases in three years, which includes all lines of business and the front, middle, and back-office of the bank. Below are selected examples from MRCB's Green Transformation Outcome Report 2018:

Pillar 1 - Green Portfolio:

MRCB mobilized resources and expertise from branches in 21 towns and villages to identify key industries and fields for climate-related financing. Successful use cases include funding smallholders to integrate rice production with crayfish farming to achieve a balanced and low-emissions ecosystem, and ensure sustainable food supplies for cities nearby. Another example is financing equipment upgrade for cold-form steel SMEs to significantly enhance energy efficiency.

Pillar 2 - Green New Business:

In 2018 alone, the bank launched 7 new green finance products and services, covering a wide range of industries. The specifics of each innovation are demonstrated in Chart 1 below.

Product Name	Description
Green Mortgage Loan	Guide clients' home purchase decisions to learn towards certified green buildings by offering preferential price and a consumer line of credit for the purchase of climate-friendly household items
Distributed Solar PV Loan	Encourage rural clients to install distributed solar system in targeted rooftop space, bringing down energy bills and generating income from sales of surplus electricity
Rural Energy Efficiency Retrofit Loan	Finance the Energy Efficiency retrofit of a significant number of old rural homes to improve living conditions and energy efficiency
Crayfish-rice Consecutive Production Loan	Encourage multi-purpose use of the same piece of farmland to enhance resource efficiency, reduce emissions, and also generate more income for smallholders
Organic Edible Lily Loan	Support the application of eco-friendly fertilizer, efficient processing lines, and Sulphur-free ovens
Green Vehicle Loan	Grant preferential car loan rates to low-emission, hybrid, and new energy car buyers. Rate discounts are commensurate with the car's environmental benefits.
Green Savings Deposit	Encourage clients to use online paperless platforms to process transactions. Green depositors will receive a customized debit card - Greenfin Card, which recognized cardholders' support for green development. Cardholders are also eligible for exclusive green services. This product helps channel deposits to green asset projects

Chart 2: MRCB's green financial products and services innovation

Pillar 3 - Strategic Commitment:

In alignment with the 2025 goal, MRCB framed its mid-term strategies on sustainability which involved three gradual steps to enable a successful transition. Furthermore, the bank also improved green capacity building for employees by enriching learning materials and increasing the frequency of course offerings. In 2018, MRBC organized 24 training workshops covering 2,158 person-times, and also established the online "Green Finance Academy" to provide a more flexible option for employees to learn at their time of convenience.

Pillar 4 - Carbon Neutral:

MRCB set up rooftop solar panels at its headquarters, which generated over 50 megawatt-hours (Mwh) of clean energy and accounted for 12.21% of the annual electricity needed. The bank also provided training and advocacy for garbage classification and recycling at the workplace and established a collaborative program to plan 50 acres of trees every year at the Bowang Hengshan Forest Farm. In addition, MRCB also reduced the energy and water use at its headquarters building by over 20% in compliance with the Edge Green Building Standard innovated by IFC and successfully received the Edge certification. To improve employees' awareness of everyday habits to reduce emissions, the bank also compiled its first edition of the "Employee Green Handbook".

Pillar 5 - Environmental, Social, and Climate Risk Management:

To ensure the transformation process doesn't lose its momentum over time, MRCB established a bank-wide green governance structure. Five transformation task forces were developed headed by the Green Bank Central Executive Office, which reports directly to Chairman and the senior management team. MRCB also set up workplace sustainability standard procedures and added 'green de-

velopment' to its corporate core values.

With a full commitment to implementation and the technical support from IFC, MRCB has achieved outstanding green transformation milestones (shown in the chart below) and is already planning on new products and training programs to continue increasing the banks' climate-related impacts.

By being the first mover, MRCB and Ma'anshan City have gotten high visibility not only domestically but internationally. Chairman Sun of the bank was invited by many global organizations and renowned institutions to speak and share his experience. What's more, through placing ESG and sustainability at the center of its operations, MRCB gained a newfound edge and branding in the market, which led to improved overall performance.

Besides MRCB, several other banks globally have also been rolling out approaches for a green transformation. What's interesting is that while the approaches taken are often tailored to the specific bank's business situations, most of the practices share similarities and can be integrated to enrich one or more pillars.

5.What Role Does Digital Technology Play?

While the digital revolution has been affecting human life and the physical world in ever-changing ways, since the start of 2020, the 'tech for development' hype has been dwindling. This is mainly due to limited funding resources in a global economy heavily affected by COVID-19, and also under such context, stakeholders are reflecting more rationally and carefully on the real value brought by each 'Frontier Technology +' prototypes developed. This trend indicates a healthy pro-

Chart 3: MRCB's green transformation milestones after the first year of plan implementation

	2017	2018	Q1 2019
Green Credit and Loans	7%	21%	28%
Green Finance Products	7%	24%	24%
Employees with Green Certificates	0	18%	69%
Buildings with Green Certificates	0	47%	47%
Emissions Reduction from Green Credit and Loans (10K tons)	18.86	60.21	95.44

cess of enhancing the efficiency and effectiveness in exploring the potential of using existing and emerging digital technologies for green banking.

Digital technologies make a difference mainly in two ways - digitization and digitalization. Digitization refers to converting physical information into a digital format, such as automating an offline documentation process that already exists. Digitalization is overhauling an organization's entire business model to create better ways of serving clients and partners. Currently, the majority of the digital-enabled projects across the public, private, and development sectors, lie in the digitization category. Meanwhile, most digitalization projects remain in the ideation proposal stage. This is somewhat expected as the exponential impacts that are supposed to generate from digitalization could only be realized when most data, processes, and interfaces involved are digitized.

For green banking, especially small and medium-sized banks, the low-hanging fruit would be using existing technologies to digitize current products and processes and improve the customer experience at a low cost, while harnessing immediate value. Meanwhile, frontier technologies such as Artificial Intelligence (AI), the Internet of Things (IoT) sensors, Big data middle platform, blockchain and such) could be used to continue exploring innovative business models through the form of minimum viable products (MVP). A few examples are given below:

Moreover, evidence shows that digital technologies can enable up to a 20% reduction of global CO_2e emissions by 2030 from 2015 levels (GeSI and Accenture Strategy 2015). Already, large technology providers are tak-

ing the initiative to identify key areas where digital technologies could offer tangible benefits for development. Namely, the Ant Group in China has made Sustainability and Women Empowerment the twin themes of its corporate social responsibility (CSR) work, and is actively pushing out initiatives enabled by blockchain, big data analytics, IoT, AI and such, to align these themes with business operations as well as facilitating partnerships with governments and development agencies. In the U.S., only four out of the 10 largest companies by market value have announced plans to reduce their emissions to net-zero by 2050. All of them happen to be technology companies: Apple Inc., Microsoft Corp., Amazon.com Inc., and Facebook Inc. Alphabet Inc.'s Google has stated that it has been carbon neutral since 2007. These engagements of large technology providers, who could potentially bring forward substantial technical capacity and R&D funding, can be critical to advancing the digitalization of the green transformation.

On the other hand, the rapid development of digital technology is also significantly driving up energy demand, potentially reversing results gained on emissions reduction. While global estimates differ widely, due to a variety of methodologies and datasets used, some evidence suggests that the total carbon emissions from the digital ecosystem have grown from 2.5% to 3.7% between 2013 and 2018 (The Shift Project 2019). The digital ecosystem includes host servers in data centers, network infrastructure (satellites, transmission media, and so on), access points (e.g., 3G base stations, modems, and wifi), and devices (personal computers, mobile devices, AI devices, and such). Working together, they consume a large amount of energy. In particular, data centers and blockchain validation processes tend to require highly complex computing and thus become extremely energy- and resource-intensive. In addition, the continued prevalence and growth of desk-top and mobile digital devices have contributed substantially to energy usage and emissions.

With the digitization and digitalization processes expected to increase over the coming decades, It is crucial to ensure that a clean supply of energy and effective energy efficiency measures are used to neutralize the overall emissions generated from the energy consumption of digital technologies.

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Analysis on the problems and suggestions of constructing a financial data factor market in China under the carbon neutral target

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Abstract

With the global climate consensus, the implementation of the carbon neutrality target has become an important starting point for China to promote high-quality and sustainable economic development, and there is an urgent need to transform the policy signal of carbon neutrality into policy dividends. The data bottleneck for the global carbon finance market will become a great opportunity for China to stand out. The construction of a data factor ecosystem for green finance will become a set of combined fiats to shape the digital green base for China's comprehensive transformation and upgrading. This article analyzes the problems and opportunities facing China's financial data factor market from the perspective of the features of data factor, basic data acquisition, data drawbacks in the energy transformation, the data linkage mechanism for green finance, the data coordination mechanism for carbon market, data value from the user side, combined with global application cases. In the end, it provides suggestions for regulators, industry organizations, platform agencies, financial institutions, international organizations, and intermediary institutions.

Key words: Carbon Neutral Target; Data Factor Market; Green Finance; Carbon Finance; ESG Investment

1.Introduction and Research Background

The Paris Agreement would not have come into being had China, the United States (US), and the European Union (EU), which together contribute more than half of all global greenhouse gas emissions, not signaled their intent to take major steps to reduce their domestic emissions. China is the world's largest source of carbon dioxide, responsible for around 28% of global emissions. Consequently, carbon neutrality has become an important step for China to promote high-quality and sustainable economic development. It is urgent to transform the policy signals of carbon neutrality into policy dividends. China aims to hit peak emissions before 2030 and for carbon neutrality by 2060 - this is a significant step in the fight against climate change. Meanwhile, the action plan of achieving peak carbon dioxide emissions has been included in China's 14th Five-Year Plan and the first compliance cycle of the national carbon emission, a global initiative to achieve net-zero emissions

by 2050. Bhutan and Suriname are the only countries that have already achieved negative carbon emissions, and six countries, Sweden, the UK, France, Denmark, New Zealand, and Hungary, have enshrined the 2045/50 net-zero emissions target in their laws. Notably, the focus of the Race to Zero campaign lies outside of government, namely cities, universities, and, crucially, investors and the private sector. A total of 995 companies worldwide have committed to achieving net-zero emissions in their operations by 2050. The global market for climate-smart businesses and technologies has grown to $1 trillion per year and is poised for accelerated growth.

Financial markets continue to play a major role in contributing to the transition to a low-carbon economy.

1.1 Dawn of China's Data Factor Era

Driven by both the technology wave and the policy dividend, the digital economy with data factor as key elements has played a pivotal role in China's economy, with the value of data becoming increasingly evident and the construction of data factor market being fast tracked.

According to the United Nations Conference on Trade and Development (UNCTAD) 2019 Digital Economy Report, data has become a new economic asset that creates and captures value, and Internet Protocal (IP) traffic, which represents data flows, has grown more than 1,500 times in 20 years. According to the analysis of *China Internet Development Report 2020*, the scale of China's digital economy has nearly doubled to 35.8 trillion yuan in the past six years, accounting for 36.2% of its GDP. And according to the statistics of the *White Paper on China Data Factor Market Development* of the Research Center of China Industrial Information Security and Development, China's data factor market is expected to reach 54.5 billion yuan by 2020, with a compound growth rate of over 30% during the 13th Five-Year Plan. Underneath the exponential growth of data value contribution to China's economy, the construction of data factor market has become a challenge for growth that must be surmounted.

In China, the wave of carbon neutrality is also accompanied by a surge of new infrastructure construction. While the economic and industrial structures are undergoing green transformation and trending towards low-carbon goals, a new wave of new infrastructure development represented by artificial intelligence, 5G, big data among others is reshaping urbanization and industrial structure upgrade. As artificial intelligence (AI) and the like free up computing power, the efficiency of data factor in all processes has been adequately liberated. With innovative technologies such as federal learning and blockchain to protect data privacy, the value of data from more participants and more dimensions of data characteristics are better reflected. Technological innovation has driven mechanism and system innovation, and the collection, calculation and utilization of carbon emission data need to integrate breakthroughs in technical efficiency and capacity of new infrastructure.

1.2 Trend Towards Carbon Neutrality Creates a Huge Funding Gap

Carbon neutrality campaign seeks to promote the transformation and upgrading of finan-

Summary of Chinese Government Policies on Climate and Environmental Information Disclosure			
Time	**Institutions**	**Policy Documents**	**Content**
2008.02	State Environmental Protection Administration	*Guiding Opinions on Strengthening Supervision and Management of Environmental Protection in Listed Companies*	Improve the coordination and information notification mechanism for environmental supervision of listed companies, and promote true, accurate, complete and timely disclosure of relevant environmental information by listed companies
2016.08	Seven ministries and commissions	*Guiding Opinions on Building a Green Financial System*	Support banks and other financial institutions to consider environmental and social risks as important influencing factors when conducting stress tests on credit asset quality, and take them into full consideration in asset allocation and internal pricing: incorporate corporate environmental information, such as information on corporate environmental violations, into the basic database of financial credit information, and establish a mechanism for sharing corporate environmental information to provide a basis for financial institutions' lending and investment decisions
2017.12	China Securities Regulatory Commission	*Standard on Content and Format of Disclosure for Companies with Publicly Developed Securities No. 2 — Content and Format of Annual Reports(Revised 2017)*	If the content of environmental information is disclosed in the form of an interim report during the reporting period, the subsequent progress or changes should be explained; companies other than key emission units may disclose their environmental information with reference to the above. If not disclosed, the reasons should be fully explained; companies are encouraged to voluntarily disclose relevant information that is conducive to protecting ecology, preventing pollution and fulfilling environmental responsibilities
2018.09	China Securities Regulatory Commission	*Code of Governance for Listed Companies (Revised)*	Establish a basic framework for environmental, social responsibility and governance (ESG) disclosure
2019.11	Asset Management Association of China	*Study on ESG Evaluation System of Chinese Listed Companies Green Investment Guidelines*	Adopt a systematic ESG investment approach, integrate environmental, social and governance factors to implement green investments, and build an environmental evaluation system and environmental evaluation database for the underlying assets
2020.01	China Banking and Insurance Regulatory Commission	*Guidelines on Promoting High-Quality Development of the Banking and Insurance Sectors*	Banking and financial institutions should establish a sound environmental and social risk management system and incorporate environmental, social and governance requirements into the entire process of granting credit.
Source: Compiled from government documents			

Figure: Summary of Chinese government policies on climate and environmental information disclosure

cial structure, industrial structure and energy structures. Carbon emission reduction with local governments as the main contributor will create a huge funding gap. Currently, direct sources of climate finance are mainly the Clean Development Mechanism (CDM) and renewable energy subsidies for electricity, and the coverage of climate finance is still limited. Based on the ecological civilization concept of "lucid waters and lush mountains are invaluable assets", the green financial reform and innovation pilot zones in six provinces and nine regions have seen remarkable success, with the balance of green loans reaching 10.22 trillion yuan at the end of 2019. The report *A Study on China's Long-Term Low-Carbon Development Strategy and Transition Pathway* suggests that achieving a 1.5°C target-oriented transition would require new investment of about 138 trillion yuan, or more than 2.5% of annual GDP. According to the forecast of *Zero Carbon China and Green Investment—Investment Opportunities to Achieve Carbon Neutrality*, the seven areas relating to zero carbon investment will shape a market of nearly 15 trillion yuan, leveraging about 70 trillion yuan of infrastructure investment. The National Development and Reform Commission approved 81 pilot low-carbon cities in batches from 2010 to 2018, while the Green Finance Committee of the China Society of Finance and Banking estimates that government finances can address only 10 percent to 15 percent of green investment needs, leaving a funding gap of about 5.6 trillion to 5.9 trillion yuan for low-carbon construction in

Summary of China's Stock Exchange Policies on Climate and Environmental Information Disclosure			
Time	**Institutions**	**Policy Documents**	**Content**
2015.03	Shenzhen Stock Exchange	*Guidelines on the Standardized Operation of Listed Companies on the Small and Medium-sized Board*	In case of major environmental pollution problems, listed companies should promptly disclose the reasons for the pollution, the impact on the companies' performance, the impact of environmental pollution, the corrective measures to be taken by the companies, etc.
2019.03	Shanghai Stock Exchange	*Rules for the Listing of Shares on the Science and Technology Innovation Board of Shanghai Stock Exchange*	Listed companies should disclose the fulfillment of social responsibility in their annual reports, and prepare and disclose documents such as social responsibility reports, sustainability reports and environmental responsibility reports as appropriate.
2020.09	Shanghai Stock Exchange	*Guideline No. 2 on the Application of Self-Regulatory Rules for Listed Companies on the Science and Technology Innovation Board of Shanghai Stock Exchange — Voluntary Information Disclosure*	SSE STAR MARKET companies may, on the basis of disclosing general information on environmental protection, performance of social responsibility and corporate governance in accordance with the provisions of laws and regulations, further disclose personalized information on environment, social responsibility and corporate governance in accordance with its industry, business characteristics and governance structure
2020.09	Shenzhen Stock Exchange	*Measures for Assessment of Information Disclosure of Listed Companies*	Listed companies can add points to their information disclosure by publishing informative and complete CSR reports, ESG reports and disclosing information on matters that are in line with major national strategic guidelines, and the results of the information disclosure assessment of listed companies will be included in the integrity file and notified to the relevant regulators of CSRC and the local securities regulator of the listed companies.
Source: Compiled from exchange documents.			

Figure: Summary of China's stock exchange policies on climate and environmental information disclosure

cities. On January 6, 2021, green finance was also included for the first time in the annual ten key tasks of the People's Bank of China to implement the major decisions and plans of peak carbon dioxide emissions and carbon neutrality, and improve the policy framework and incentive mechanism of green finance.

The financial data factor market under the carbon neutrality target examined in this paper is thus defined in two ways: first, the capitalization of the data factor market with the carbon neutrality target as a constraint; and second, the convergence of the green financial market and the data factor market. While data factor is included as one of the five factors of production in China and the climate investment and financing market is about to witness explosive growth, it is important to study how to build China's financial data factor market in the light of the goal of carbon neutrality.

First, we must respond to the global trend of actively addressing climate change, transform China's policy signals into policy dividends, explore a sustainable ecosystem that integrates green economic development and carbon emission reduction, and build an international community in pursuit of carbon neutrality. The second is to respond to the trend of the fourth industrial revolution and China's active promotion of new infrastructure such as artificial intelligence and big data, to build a data factor market with green characteristics, to pave the way for the circulation of data factors, to accelerate the digitalization process in energy transformation and the capitalization

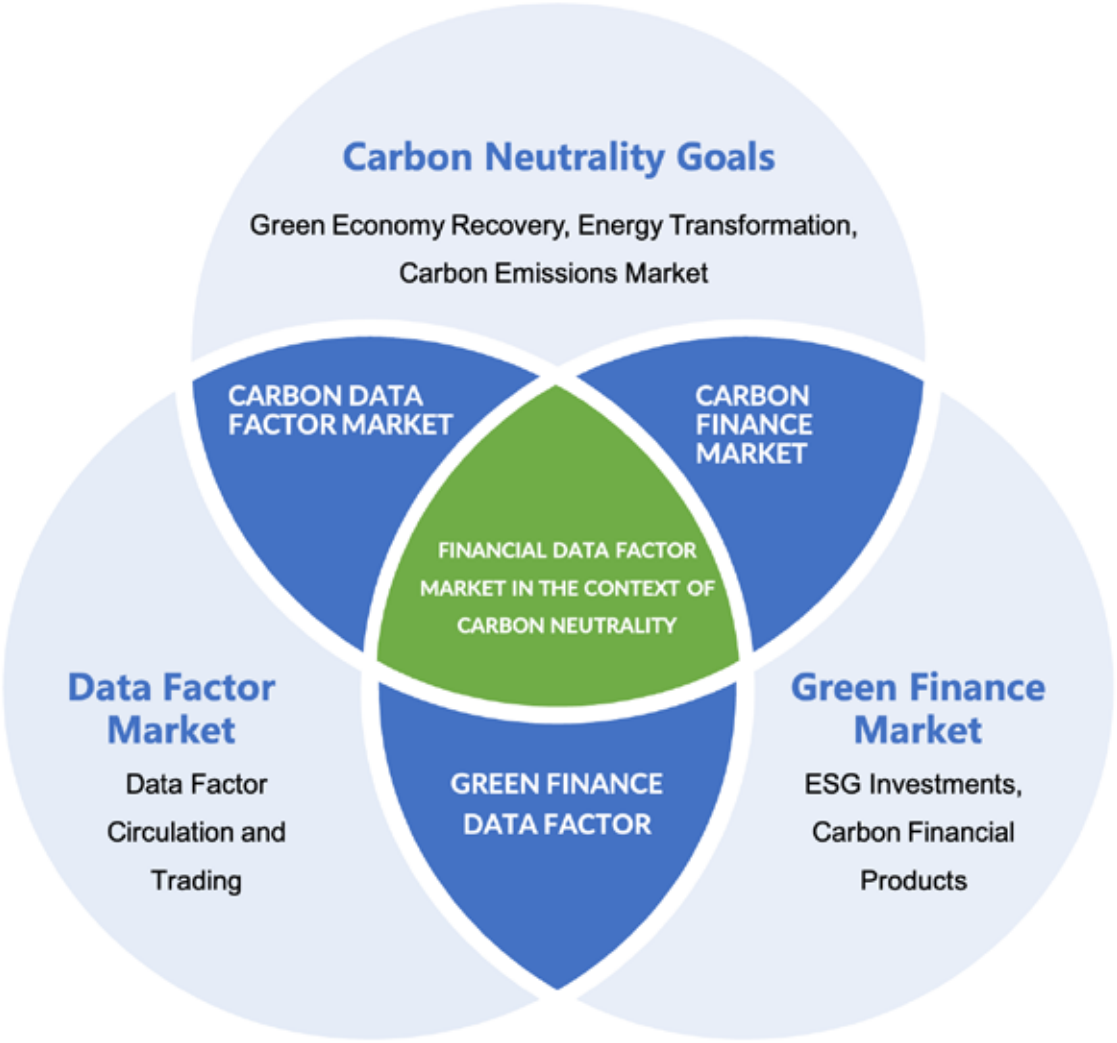

Figure: Definition of Financial Data Factor Market in the Context of Carbon Neutrality

process of financial and data factor transformation, and to leverage the characteristics of data factor to push forward the demand-side reform in return. This paper focuses on the characteristics of data factor, basic data collection, data shortcomings in energy transformation, data convergence mechanism of green finance, regional synergy mechanism of carbon market, data value of small and micro enterprises and individual users, etc. Combining with global cutting-edge application cases, it provides an in-depth analysis of the problems and development opportunities of the current data factor market associated with carbon finance in China. Lastly, it proposes suggestions for building an ecosystem consisting of regulators, industrial institutions, platforms, financial institutions, international organizations and intermediaries.

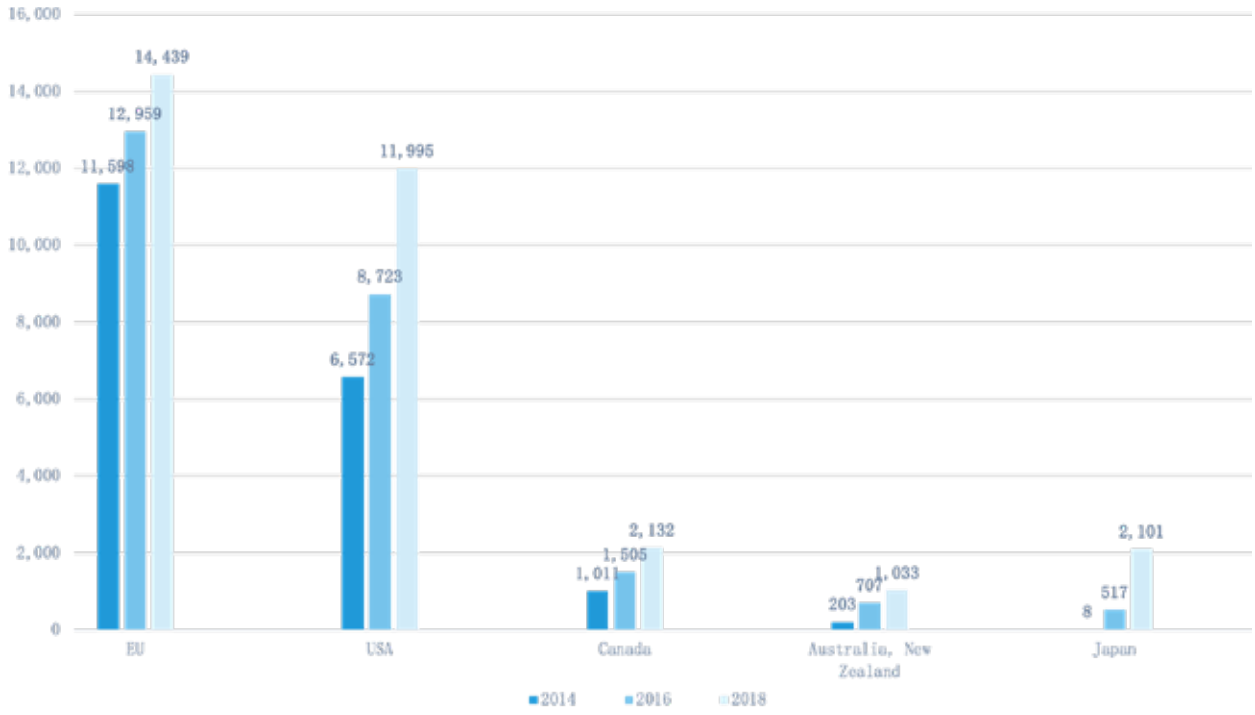

Figure: Changes in the Scale of Responsible Investment in Major Developed Economies Worldwide
(Unit: $1 billion. Source: Global Sustainable Investment Alliance)

2.Analysis of Global Sustainable Finance Trends

Globally, sustainable investment and climate finance have become the consensus to address climate change and guide a virtuous cycle of finance. According to the statistics from the Global Sustainable Investment Alliance, the total amount of specialized assets under management in major economies around the world based on the concept of responsible investment reached $30.68 trillion in 2018, up 34% from 2016.

Underneath the rapid growth, the disclosure of information based on climate change and environmental indicators has become an essential tool for regulation. According to Refinitiv's ESG (Environmental, Social, Governance) Investment Report, the number of ESG-related regulations worldwide has nearly tripled as of September 2019 compared to 2015, with governments and international organizations becoming the main drivers of standards innovation.

Source: Insights and Lessons for China from the Mandatory Environmental, Social and Corporate Governance Information Disclosure System for International Listed Companies, Changjiang Stock Exchange

Framework for Environmental and Climate Information Disclosure in Developed Economies			
Economies	**System**	**Main Participants**	**Primary Basis**
EU	Semi-Mandatory	Relevant institutions of the EU and the Member States	*Non-Financial Reporting Directive*, *EU Taxonomy: Final Report of the Technical Expert Group on Sustainable Finance*, *Shareholder Rights Directive*, *European Green Deal*, *Action Plan on Sustainable Finance*, etc.
Japan	Semi-Mandatory	Tokyo Stock Exchange, Japan Exchange Group	*Code of Corporate Governance*
USA	Mandatory	The U.S. Securities and Exchange Commission, The United States Environmental Protection Agency, Financial Accounting Standards Board	*Securities Act*, *Clean Water Act*, *Solid Waste Disposal Act*, *Resource Conservation and Recovery Act*, *Pollution Prevention Act*, *Toxic Substances Control Act*, *Comprehensive Environmental Response, Compensation, and Liability Act*, *Emergency Planning and Community Right-to-Know Act* (EPCRA), *An Introduction to Environmental Accounting as a Business Management Tool: Key Concepts And Terms*
France	Mandatory	French Accreditation Committee (Cofrac), notified bodies of the European Union, collaborating organizations, third-party institutions, The French Government	*Revised bill for energy conversion in the Grenelle Acts*
UK	Mandatory and Voluntary	UK Listing Authority (UKLA), London Stock Exchange	*Companies Act*, *Environmental Protection Act*, *Corporate Governance for Main Market and AIM Companies*, *Environmental Reporting Guidelines*, *Guidance on Streamlined Energy and Carbon Reporting*
Singapore	Mandatory and Voluntary	Singapore Exchange Limited, Monetary Authority of Singapore	*Code of Corporate Governance*

Disclosure Requirements for Principal Responsible Investment Organizations					
Standard Setters	**Focus**	**Guidelines or Standards**	**Based on Specific Industries?**	**Based on Financial Data?**	**Form of Disclosure**
Global Reporting Initiative (GRI)	Environment and Society	Standard	No	No	Corporate Financial Reports
Sustainability Accounting Standards Board (SASB) Foundation	Environment, Society and Governance	Standard	Yes	Yes	Corporate Financial Reports
Task Force on Climate-related Financial Disclosures (TCFD)	Climate Change	Guidelines	Yes	Yes	Corporate Financial Reports
Principles for Responsible Investment (PRI)	Environment, Society and Governance	Guidelines	No	No	Corporate Financial Reports
Integrated reporting (IR)	Finance, Environment and Society	Standard	No	Yes	Comprehensive Report
Climate Disclosure Standards Board (CDSB)	Climate Climate and Natural Capital	Standard	No	Yes	Corporate Financial Reports
Carbon Disclosure Project (CDP)	Carbon, Water and Forests	Questionnaire	Yes	No	Questionnaire
Source: BloombergNEF					

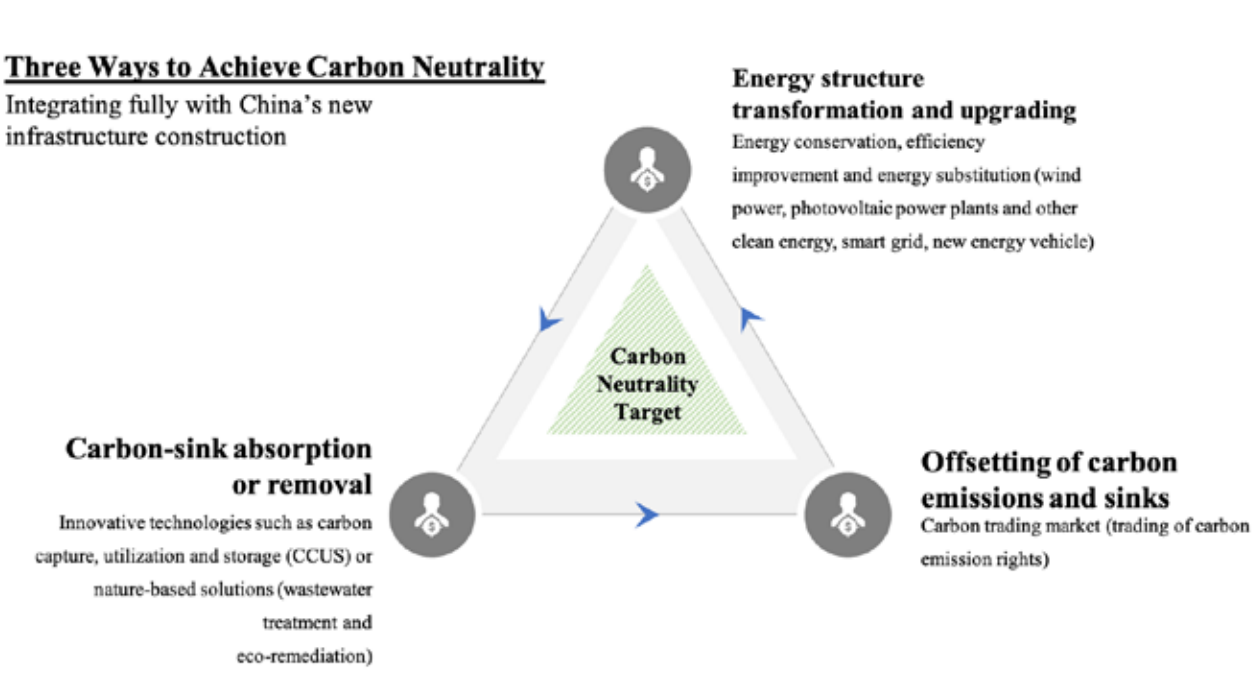

Figure: Three Ways to Achieve China's Carbon Neutrality Goal

3.Problem Analysis and Global Case Study

The realization of carbon neutrality depends on three primary approaches. The first is to transform the energy mix and reduce carbon emissions through energy conservation, efficiency improvement and energy substitution. The second is to achieve carbon-sink absorption or removal through innovative technologies such as carbon capture, utilization and storage (CCUS) or nature-based solutions. The third is to use carbon trading markets and other means to realize the offsetting of carbon emissions and sinks. Among these three approaches, financial instruments guarantee capital support for the energy transition and carbon sink process, as well as the unique financial attributes of the carbon market itself. Therefore, when analyzing the issue of building China's financial data factor market in the context of carbon neutrality, we need to approach it from the perspective of the characteristics of data factor itself, basic data collection, the process of energy transition, the datafication of green finance, the data synergy mechanism of carbon market, and the user-based universal inclusion.

3.1 The Quasi-Public Attributes of Data Factor

The data factor as a type of quasi-public goods, may lead to a failure of market utility. According to Samuelson's public goods theory, data factor is typically non-competitive and non-exclusive. It is non-competitive in the sense that climate and environment-related data factors can be permanently stored and replicated in most scenarios without incurring "crowding costs" and without decreasing their utility as the number of users increases, i.e., the marginal utility is not diminishing; it is non-exclusive in the sense that the cost of preventing people from consuming data factors is infinite, and there are multiple

sources of climate and environment data collection and circulation, which are difficult to limit effectively. Deficiencies in public goods will lead to diminishing or even dysfunctional market utility. Ecology has obvious externalities. The negative externalities caused by carbon emissions need to be internalized locally by companies and individuals. In fact, as a "club product", data factor is completely non-competitive but with comparatively low exclusion cost. On the one hand, standards should be set to guarantee the overall basic benefits. On the other hand, the value of data factor can be effectively measured and paid precisely through technical means to attract the participation of social capital, such as the carbon footprint data of circulation links to stimulate the consumption of green assets. For the characteristics of data factors themselves, there is a lack of a systematic mechanism design for data ownership, trading and incentive mechanism. In addition, given the general trend of increasingly strict regulation of data privacy and security, especially in energy transformation involving the core assets of national strategic energy enterprises and major strategic areas of data, which are among the key areas of supervision and regulation, there is still a significant risk of data security.

3.2 Carbon Emission Data Collection and Boundary Definition

The collection of carbon emission data from production activities and the definition of boundaries are the main fundamental issues faced in the process of enforcing carbon neutrality. MRV (Monitoring, Reporting and Verification) refers to the process of quantifying carbon emissions, which is a fundamental element in building a carbon trading mechanism and an important basis for enterprises to undertake low carbon transformation and pursue carbon neutrality. Since 2011, after China launched eight provincial (municipal) carbon emissions trading pilot projects, each pilot region has established its own relatively complete MRV system, thereby paving the way for the formation of a MRV system for a unified nationwide carbon market. However, at present, China's carbon emission monitoring, reporting and verification for corporate entities are mainly focused on eight industries, including petrochemical, chemical, building materials, iron and steel, non-ferrous, paper, electric power and aviation, and enterprises or other economic organizations with greenhouse gas emissions of 26,000 tons of carbon dioxide equivalent or more. There is a lack of systematic, digitized and organized system to support the collection and boundary identification of carbon emission data for a large number of Small and Micro Enterprises outside the scope. The application of third-party verification system, which is commonly required for large market players, also suffers from shortage of supply capacity, high price and lengthy audit process for SMEs. The dilemma of lack of carbon emission data will prevent many types of market players from participating in the carbon cycle.

3.3 Data Shortcomings in Energy Transformation

There are a serious data shortage in the process of energy transformation like inefficient data utilization, and a need to shift from supply-oriented practices to demand-oriented practices. In 2016, China issued the Guidelines on Promoting "Internet+" Smart Energy

Development, which proposed to reshape the energy industry chain, supply chain and value chain, achieve multi-energy complementarity, and promote the efficient operation of production, transmission, trading and consumption. Although the Industrial Internet is incorporated into the national strategy for new infrastructure, the digital transformation in energy transformation is still focused on the electronicization of energy data, i.e., the digitization of energy management and processes, which is still not data-driven in terms of production relationships and demand management. Moreover, there are obvious silos of energy data between different organizations, preventing the flexible flow and even secondary development and transformation within the industry.

As an industry that accounts for nearly 50 percent of China's carbon emissions, emissions reduction from power generation is the focus of energy structure transformation, but intelligent emissions reduction is still at a relatively preliminary stage. In terms of international practices, DeepMind, a subsidiary of Google, has applied machine learning algorithms to a 700 MW wind power generation project in the Central U.S. Using weather forecasts and historical data from wind turbines for neural network training, it is possible to predict power output 36 hours before actual generation. In addition to developing energy replacement strategies represented by clean energy and improving energy use efficiency, another major breakthrough is the implementation of flexible response and data-driven distribution demand reform supported by innovative technologies such as flexible power distribution. Different from the previous large-scale centralized grid synchronization and unified purchase and marketing model, the future power consumption will be gradually optimized by time-sharing tariffs, intelligent distribution and other methods, and the large-scale application of smart home appliances and electric vehicles has put forward higher requirements for the refined use of data.

For example, in sub-Saharan Africa, where nearly two-thirds of the population does not have access to the main grid, British photovoltaic company Azuri Technologies has developed a pay-per-use smart solar solution to address household electricity challenges in East Africa and Nigeria. Azuri's HomeSmart solution is based on artificial intelligence technology and uses off-grid solar technology to track a home's energy needs in real time and adjust power output accordingly (e.g. by automatically dimming lights) to meet the user's daily needs and encourage the use of appliances such as televisions based on this and regular access to the network. According to the statistics of the Overseas Development Institute (ODI), the use of solar power is predicted to reduce African households' lighting expenses from nine percent to two percent, providing electricity to at least 500,000 households in East Africa. This is also highly relevant to the vast remote mountainous areas of China. In addition, the more personalized and precise electricity demand for micro and small enterprises and individual customers will also become an important data feature to reshape the production-transmission-consumption process, and may even become an important indicator to examine the business environment in the context of carbon neutrality.

3.4 Climate and Environmental Information Disclosure

Compared with the developed green finance markets around the world, China's green finance still has more room for growth in terms of scale and quality, and the maturity of data and the degree of information disclosure need to be further enhanced. The Central University of Finance and Economics estimates that in 2019, China's new demand for green finance funds will be 2.048 trillion yuan, with a funding gap of 0.618 trillion yuan, or more than 30 percent. One important reason underneath this is the lack of sufficient data support and a unified information disclosure system, leading to a large variability in green financial standards and thus a lack of supply of green financial products. In particular, with carbon neutrality as the constraint, the perfection of green finance standards and data needs to be benchmarked against global standards at the outset to form a green finance pathway plan with Chinese characteristics. Taking ESG investment as an example, in China, during the nearly ten years from 2011 to 2020, the disclosure of annual CSR reports in China's A-share market has grown from 565 in 2011 to 1,005 in 2020, accounting for just under 25 percent. Unlike traditional financial reporting, which requires mandatory disclosure, ESG investment-related information is mostly disclosed in companies' own CSR reports or relies on subjective expert ratings, leaving room for individual companies to "greenwash" and easily raise funds under the guise of green investments. On the one hand, because of the lack of uniform standards, there is a shortage in the structure and objectivity of the data, and it is impossible to verify the authenticity of the data. On the other hand, because earnings reports or CSR reports are mostly disclosed once every six months or once a year, it is not possible to provide timely feedback on climate risks in terms of timeliness and to guide the flow of funds to the market in a timely manner. China's capital market is developing in scale while focusing on quality improvement. Financial indicators alone can no longer address the current scenario of frequent environmental events. Climate-related data factors can help identify non-financial factors performance to eliminate investment targets that may have long-term systematic environmental risks and ensure long-term stable returns.

Taking note of advanced international cases, on October 29, 2019, the World Bank made public for the first time a database of countries and regions used for ESG investments. A total of 17 indicators, such as greenhouse gas emissions, population change and the degree of progress in gender equality, for each country in the world are monolithized and the data can be retrieved by anyone through a dedicated website. The goal is to drive investment capital to emerging economies that are actively committed to sustainable investment by providing investors with a way to determine which countries and regions are committed to ESG investing.

At the same time, the current Chinese green investment and financing system has limited support for innovation in technological achievements related to the carbon market. According to a report by the China Association of Environmental Protection Industry, the proportion of Research and Development expenditure to business revenue of the 10,000

environmental protection enterprises participating in the survey was only 3 percent, far below the average of 3.8 percent in developed countries.

According to Paul Romer's endogenous growth theory, the ultimate driving force to sustain long-term economic growth is the continuous emergence of new technologies, and the data factor, as one of the factors of production is the prime motivator of innovation in technological achievements. For example, Unilever is committed to achieving net zero emissions for all its products by 2039. To reach its goal, it is working with suppliers to measure the carbon footprint of its products and use satellite and blockchain technology to improve data traceability and transparency in its supply chain, create biodegradable formulations, and establish a €1 billion climate and nature fund to invest in land regeneration, water and reforestation. The International Union for Conservation of Nature (IUCN) led the establishment of the Nature+Accelerator Fund, the first nature conservation accelerator fund dedicated to the private sector, to accelerate the translation of technology to meet pressing conservation challenges and provide investors with the opportunity to balance the promotion of conservation, positive social impact and reasonable financial returns. Therefore, this requires both the deployment of national-level green financial support programs and local supporting funds for technologies that address climate change, as well as actively guiding social capital and even international investment to participate in promoting the transformation of technological innovation through public-private partnership (PPP) and other means, and improving climate information disclosure requirements at the project level.

3.5 Data Synergy Mechanism for Carbon Market

Currently, the Chinese carbon market lacks a data synergy mechanism. According to the data of the People's Bank of China, the global carbon finance market has an annual transaction scale of more than 60 billion dollars. By the end of 2019, the cumulative turnover of carbon market quotas in seven provinces (cities) was only 356 million tons, with an amount of more than 7.3 billion yuan, the market potential needs to be further explored, and the carbon price is relatively low in the world. It is necessary to set up an authoritative carbon trading certification mechanism to align with the international market. The core factors of the carbon market trading system include the allocation of total allowances, monitoring and verification of emission data, trading mechanism, offset mechanism and compliance mechanism, etc. Unlike the traditional financial market with mandatory financial disclosure requirements or professional intermediary intervention, the whole process of the carbon market is subject to data tracking and monitoring.

With the gradual progress of China's carbon market and carbon emission rights pilot scheme, the carbon-centered cities represented by Beijing, Shanghai and Shenzhen will link up with neighboring cities to form regional carbon trading platforms and mechanisms, and the circulation of data elements related to the carbon market within and across regions will become more and more frequent. On the one hand, the data factors guarantee

the professionalism and objectivity of carbon trading and can realize cross-regional certification mechanisms, so as to better realize the cross-regional eco-compensation. On the other hand, the carbon emission quota trading, which is the core of the carbon market, is more conducive to trading with data factors and realizing the carbon price discovery function. Taking international practice as an example, the European Union Emissions Trading System is the world's largest carbon emissions trading market, and has cultivated a multi-level carbon emissions trading market system, with regional and industry trading centers such as the European Climate Exchange, the Northern Power Exchange, the Future Power Exchange and the European Energy Exchange coming into being, and derivatives markets such as carbon emission rights options gradually taking shape. Facing the problem of insufficient micro data such as enterprise level data, the system has established a huge database of enterprise carbon emissions through continuous investigation and correction from enterprises, which has provided data for the whole EU ETS.

3.6 The Absence of Green Finance in Micro and Small Enterprises and Individual Users

Green financial services don't have enough coverage on small and micro enterprises and individual users, and the value of data is not fully explored. According to the data of the People's Bank of China, a total of 13.7 million small and micro enterprises are included in the People's Bank of China's enterprise credit system, and 3.71 million of them have received credit support, accounting for 14 percent. As a vital force in the private economy, the total number of small and micro enterprises is large and covers a wide range of areas. However, there is a serious shortage of supply in the corresponding green financial services, which is limited by problems such as insufficient credit data, thus making it difficult to attract small and micro enterprises to participate in upgrading around the carbon cycle. In addition, from the perspective of inclusive finance, individual users should have more weight in the carbon finance system, and the current carbon finance data of individual users are fragmented and difficult to track. A data-driven system of carbon consumption and accounts is needed to address this challenge. First of all, thanks to the rise of mobile internet, the emergence of cashless payments, Internet loans and other methods, efficiency has been greatly improved. Especially in the face of COVID-19's impact on the economy, coupons launched nationwide can be more precisely linked to offline spending scenarios. Therefore, to promote low-carbon lifestyle, it is possible to design a multi-participation carbon spending mechanism by joining the government, enterprises and financial institutions at the beginning. Of course, in the context of China's "credit society", personal carbon accounts can be tied to credit points, and carbon accounts and personal data accounts can be connected and used in scenarios such as electric car charging piles, public transportation and cycling services, waste separation and green product purchases. In September 2018, Shenzhen Green & Low-Carbon Development Foundation launched "Carbon Account Version 4.0", which records personal carbon emission data on the one hand and emission reduction through energy saving and environmental protection on the other hand, and establishes carbon footprint tracking and incentive mechanism through "carbon

Figure: Definition of Financial Data Factor Market in the Context of Carbon Neutrality

diary" and challenges. It ties public services such as public travel with low-carbon life scenarios, solving the dilemma that it is difficult to collect personal user data and participate in financial services.

4.Suggestions for Building China's Financial Data Factor Market in the Context of Carbon Neutrality

With the goal of carbon neutrality, the data bottleneck common to the global carbon finance market will also become a golden opportunity for China to stand out, and the construction of green finance and data factor ecosystem will become a set of combos to shape the digital green base for China's comprehensive transformation and upgrading. Achieving the goal of carbon neutrality is a transformation and upgrading of the financial structure, industrial structure and energy structure in multiple parties and a reinvention of the whole process. Therefore, the construction of China's financial data factor market in this context requires the coordinated cooperation of six parties, including regulators, industrial institutions, financial institutions, platform institutions, international organizations and professional intermediaries.

4.1 Regulators

From the perspective of regulators, a four-pronged management system of ownership,

pricing, trading and governance should be established based on the characteristics of data as a type of quasi-public goods. In terms of regulation of market construction, we should take the carbon neutrality as the constraint, establish the concept of "One Country, One System", build a unified standard for climate investment and financing and green finance, and set the definition and performance evaluation standards for climate projects, so as to regulate and guide the determination of ownership and pricing of data factors. At the same time, to promote trading, a graded and classified asset catalog of public green data resources can be established based on value, security and other indicators. We should gradually proceed with opening up in the form of pilot projects, with clear specification of ownership and responsibility for the parties involved in trading, and gradually promote the integration of public and private data. We should establish a green financial incentive mechanism centered around carbon emissions, promote the establishment of a professional trading platform for green assets and a trading platform for data elements based on green industries, and establish a traceable and verifiable data review and tracking mechanism to guide and regulate multiple parties such as large enterprises, small and micro enterprises, and individual users. In the regulation of data security, we need to establish a three-dimensional penetrative management system, create a graded data security governance mechanism, and encourage progressive data innovation through regulatory sandboxes and other means. In terms of coordination among multiple government departments, a special action and coordination office should be established across multiple ministries such as the NDRC, the Ministry of Ecology and Environmental Protection, the Ministry of Science and Technology, the Central Bank, and the CBRC to supervise and guide communication and coordination involving the central government, local authorities and different functional departments. Meanwhile, a number of exemplary models with local characteristics should be established for the rest of the lot to follow. Specifically, there are obvious regional differences in the rights of use and charging mechanisms for sewage and waste disposal, such as waste emission rights, carbon emission rights, forest land management rights, electricity trading rights, etc. Moreover, they are under the management of different commissions and bureaus, which require the formation of a unified planning design and division of tasks and the implementation of a flexible synergy mechanism.

4.2 Industrial Institutions

From the perspective of industrial institutions, we should seize the two opportunities of industrial digital transformation and green transformation. Regarding the promotion of green industry development, it is necessary to transform the traditional crude production and operation methods and shift to low-carbon industries while promoting the construction of a low-carbon and efficient energy supply system. Taking the "Industrial Smile Curve" proposed by the Chairman of Acer, Shi Zhenrong, as an example, the data factor market also meets the distribution of the value curve. Therefore, on the one hand, through financial means and technological innovation, we can engage in high value-added links in the global industrial chain, such as technological innovation in the upstream of the in-

dustrial chain or branding and service links in the downstream, so as to improve the production efficiency per unit of GDP and reduce energy consumption per unit at the same time; on the other hand, we should take data factors as a point of entry, accelerate the use of digital technology to develop emission data for small, medium and micro market players and individual users, and accelerate the construction of carbon neutral data infrastructure. The energy saving, efficiency and energy substitution aspects of energy transformation will generate a large amount of data, with the help of which we can promote the process of data-oriented energy Internet and industrial Internet, deploy production on demand, adjust production plans and establish a hierarchical data asset system. In addition, industrial institutions can use the advantages of federal learning, multi-party secure computing, blockchain, trusted computing and other technologies in "data availability and invisibility", "quantitative and targeted precise use", and traceability to establish a safe and credible industrial data sharing mechanism and a flexible and responsive energy use strategy based on user needs, improve the efficiency and accuracy of traditional industrial algorithms, promote the transformation and reuse of scientific and technological innovation results, and promote the circulation of data factors in the same industry and between different fields. In addition, we should leverage climate investment and financing instruments, and actively use PPP and other models to open up opportunities for social capital to participate in the energy transformation. The first is to participate in carbon emission rights trading in the primary market, and the second is to participate in derivatives trading in carbon stock, carbon futures and carbon options in the secondary market, so as to rationalize resources by financial means. At the same time, we can apply the ESG (Environment, Social, and Governance) framework to information disclosure and internal governance, and apply data factors to manage financial risks throughout their life cycle and provide timely warnings.

4.3 Platforms

From the perspective of platforms, we have to bring into play the role of traditional financial exchanges and professional exchanges represented by carbon emission exchanges. For traditional exchanges such as the SZSE, we should encourage trading of financial products in line with carbon neutrality and climate change trends and trading of scientific and technological property rights relating to energy transition, improve green financial product lines such as bonds, funds and trusts in the context of carbon neutrality, strengthen data governance and information disclosure requirements for listed companies and financial institutions on ESG and climate risks, establish regional trading platforms and mechanisms for Guangdong, Hong Kong, Macao, the Greater Bay Area, Beijing, Tianjin, Hebei and the Yangtze River Delta, promote the convergence and circulation of financial data elements in the region, and encourage private and foreign capital to participate in the pursuit of China's carbon neutrality goals. For professional exchanges such as the carbon emissions exchange, we should bring into play the functions of carbon price discovery and cross-regional ecological compensation, assume the dual roles of trade regulation and market coordination, explore the

pricing mechanisms of various green factors, promote the innovation of derivative products and financial products such as carbon futures, introduce various data sources such as satellite data, public opinion data and Internet of Things monitoring data to cross-validate carbon emissions data, and establish a data tracking and feedback mechanism.

4.4 Financial Institutions

Financial institutions should promote the innovation of various carbon financial products and increase the proportion of ESG and climate investment and financing in financial products. First, we should follow the green finance standard in the context of carbon neutrality, bring into play the role of data factors in information disclosure and tracking, strengthen the control intensity of climate risk in the whole process of "fundraising, investment, management and withdrawal" of financial products, leverage artificial intelligence technologies such as natural language processing and knowledge mapping to build a carbon risk transmission analysis system based on the green industry chain and green supply chain, combine multiparty privacy and security calculation, blockchain and other means to expand the dimension of data features without infringing on data privacy, introduce legal and effective third-party data, carry out stress tests and scenario analysis, and conduct carbon finance footprint analysis. We should combine multiple privacy security calculations, blockchain and other means to expand the dimension of data characteristics without infringing on data privacy, introduce legal and effective third-party data, carry out stress tests and scenario analysis, and carry out carbon finance footprint tracking. Secondly, we should explore asset securitization means for green assets, enhance the liquidity of carbon finance products, and use the PPP model to encourage social capital to participate in the energy transformation process. Third, we should target small and micro enterprises and individual consumers, introduce credit services and payment services that are compatible with low-carbon lifestyles, establish carbon accounts and build a closed loop of carbon-based lifestyles, and encourage ecological partners to participate in creating low-carbon spending scenarios with local characteristics.

4.5 International Organizations

International organizations should bring into play the role of leading international standards and guiding the flow of capital. In terms of leading international standards, as the main force of the global initiative for carbon neutral targets, the United Nations can establish data monitoring and linkage mechanisms in specialized areas such as carbon sinks, carbon taxes and carbon trading, and establish a global coordination mechanism for data elements led by the United Nations. Task Force on Climate-Related Financial Disclosure (TCFD), Carbon Disclosure Project (CDP), and other Chinese regulators should be encouraged to work together to regulate and guide corporate disclosure and climate risk analysis. The Network of Central Banks and Supervisors for Greening the Financial System (NGFS), initiated by central banks and regulators in eight economies, such as China and France, can align standards at the top level, especially for stress testing and scenario analysis of their respective actions based on global carbon neutrality targets.

In terms of directing capital flows, the World Bank Group and other multilateral financial institutions can increase the degree of information disclosure on climate investment and financing activities in which they participate in China, create exemplary investment examples, and at the same time work with Chinese financial institutions to improve the scope and depth of access to green financial services, with a particular focus on supporting energy transition projects and small and micro enterprises.

4.6 Intermediaries

Sixth, from the perspective of intermediaries (law firms, accounting firms, consulting teams, rating agencies, etc.), we have to fulfill the role of professional support and regulatory guidance in the ecology. On the one hand, we should provide professional support, draw on international case studies and international standards, provide an assessment framework for sustainable investment to meet China's carbon neutrality target, provide third-party data verification and evaluation, and help China export its experience in "carbon neutrality"; on the other hand, we should bring into play the standardization and guidance role of professional organizations, starting with industries, and work together with industry associations to launch industry implementation guidelines and white paper reports, so as to standardize and guide the trends and find industry benchmarks.

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CHAPTER FIVE:

CALL FOR ACTION

Call for Action

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Of all the greenhouse gases, CO_2 is regarded as the main culprit behind most of the negative climate change impacts given the abundant human production of this gas since the industrial revolution began. As the primary byproduct of fossil fuel consumption, CO_2 is generated in a variety of industries such as transportation, the building and construction, energy and mining industries and others.

Over half the world's population live in cities today and the numbers are rising rapidly which means our urban centres will play a critical role in determining whether or not the world's climate goals are met. As has been noted, today, cities account for about 75 per cent of the world's energy consumption and are responsible for over 70 per cent of global greenhouse gas emissions. Noteworthy, the way cities are planned, built and managed, is key to reducing carbon emissions and keeping global warming within the limits set by the 2015 Paris Agreement on Climate Change.

UN-Habitat recognises the critical role of cities in combating the defining crisis of our time and continues to partner and work with them to accelerate urban action for a carbon-free world. Through various initiatives UN-Habitat has continued to amplify the global Race to Zero Campaign and encourage local governments to develop actionable zero-carbon plans. Hundreds of cities around the world have made commitments to become completely carbon neutral by 2050 - will not produce any more climate-changing emissions than they can offset.

It has been estimated that Greenhouse Gas emissions from cities can be reduced by almost 90 per cent by 2050 using technically feasible, widely available mitigation measures. This means that city actions can potentially reduce global emissions by over 70 per cent. This potential reduction can be achieved through a combination of measures that target the urban form in expanding cities as well as the buildings, transport, material efficiency and waste management sectors.

There are many ideas and lessons that have emerged from the articles in this publication. Many are worth noting as they provide practical advice to urban policy makers and urban managers on how they can strengthen their climate commitments.

Some of the required actions include to;

1. **Build energy efficient infrastructure and housing:** Much of the carbon emissions in cities come from heating, lighting and cooling buildings and homes. Towns and cities need to build energy efficient infrastructure and housing designed for local conditions. At the same

time existing buildings must be retrofitted by implementing measures or technologies to make them more efficient such as improved insulation or ventilation so they use less energy. Also, new buildings must be constructed using materials which do not produce carbon dioxide while being extracted or manufactured and that are energy efficient.

2. **Promote and implement diverse urban mobility solutions:** Transport via road, rail, air and water generates approximately a fifth of carbon dioxide emissions – the majority coming from road transport. Low-carbon public transport integrated with facilities for walking and cycling will help tackle this issue. Walking and cycling are the cleanest ways to get around a city, and both can have enormous benefits for health, greenhouse gas emissions, air quality, road safety and equity.

3. **Plan compact cities:** Urban planning can steer urban growth towards low carbon urban development through advancing climate-friendly urban forms. Ensuring that growing cities are compact, and that expansion takes place in a planned manner to accommodate the growing number of residents helps reduce their carbon footprint. Compact cities also make the provision of basic services such as waste management, transport, energy and water and sanitation more resource-efficient and financially viable. Planning compact cities where people can reach their work and facilities within a short distance will also reduce emissions.

4. **Generate clean energy:** Countries need to generate clean, resource-efficient energy which is cheaper than ever before and move away from fossil fuels. This will also bring about health-related benefits, for example by reducing air pollution and can generate green jobs. Economic sectors and industries should use more renewable energy in production. Cities, the main centre of energy demand, must lead the Race to Zero. Cities should take the lead in starting from leading industries and pillar industries, find out the *status quo* of carbon emissions in the industrial chain, regularly sort out the "carbon-neutral industry opportunity list" according to the frequency and emissions of carbon emission activities in production scenarios, and actively help enterprises find green science and technology to promote industrial upgrading.

5. **Promote urban green spaces to help reach carbon neutrality:** Public and green areas play a key role as carbon sinks, in regulating temperature and reducing urban heat-island effects. Simultaneously, measures can be taken to improve access to basic services while reducing their carbon footprint. These could include better water demand management, waste-water treatment through nature based solutions, better municipal waste management and material recovery, uptake of micro-grids, renewable energy and net-metering, retrofitting buildings to improve their energy efficiency, promoting a transition to shared and public transport and the uptake of electric mobility.

6. **Utilize innovative ways to reduce greenhouse gas emissions in cities:** Under the global value-oriented changes that are being green and low-carbon, the urban living scene laboratory may also be an effective governance model exploration, which makes cities prepare for the new wave of integration of digitalization and decarbonization the two industries. Urban Living Labs orchestrates collaboration, bringing together the different stakeholders - companies, research institutions, the public sector and citizens - through co-creation. Co-creation involves different phases of development to reach the final solution. Chengdu is pioneering in developing “Park City” deploying new economic methods, which is likely to be an integration of smart city and green-low carbon city. Efforts must be made to utilize innovative ways to reduce greenhouse gas emissions in the city while creating other social benefits.

7. **Put in place mechanisms to attract funding from private finance actors**: Getting metropolitan areas to environmentally neutral states will require substantial funding injections not only from the fiscal bodies but also from the private finance actors. Investors and businesses are playing a central role in the transition to a green economy. Investments focused on environment, social and governance factors have surged recently. Cities in collaboration with national governments can attract investments, for example, for smart energy grids and buildings through enabling policies and incentives and by show-casing innovative projects. Private sector financing is crucial to a successful green transition. The financial sector, and commercial banks in particular, therefore have an important role to play - not only through providing sustainable financial products and services, but also by influencing other sectors in a variety of ways including sustainable investment trends and innovations in operations.

8. **Enhance public participation and maintain technological openness:** Transparent and open government management system and government service information platform should be built to enhance public participation and make the government's planning and design public in real time. Additionally, there is need to strengthen publicity and guidance, promote the awareness of local governments and relevant subjects, combine the construction of demonstration projects with local economic and social development, and drive the formation of green and low-carbon new growth points and new drivers through the projects, so as to achieve a win-win situation between carbon emission control and economic development. Achieving climate goals requires maintaining technological openness.

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IMPLEMENTING THE NEW URBAN AGENDA