Environmental Science and Ecotechnology 8 (2021) 100130

Contents lists available at ScienceDirect

Environmental Science and Ecotechnology

journal homepage: www.journals.elsevier.com/environmental-science-and-ecotechnology/

Original Research

Towards carbon neutrality and China's 14th Five-Year Plan: Clean energy transition, sustainable urban development, and investment priorities

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ARTICLE INFO

Article history:
Received 1 July 2021
Received in revised form
10 October 2021
Accepted 11 October 2021

Keywords:
Carbon neutrality
14th Five-Year Plan
Energy transition
New urbanisation
Investment

ABSTRACT

China's 14th Five-Year Plan, for the period 2021–25, presents a real opportunity for China to link its long-term climate goals with its short-to medium-term social and economic development plans. China's recent commitment to achieving carbon neutrality by 2060 has set a clear direction for its economy, but requires ratcheting up ambition on its near-term climate policy. Against this background, this paper discusses major action areas for China's 14th Five-Year Plan after COVID-19, especially focusing on three aspects: the energy transition, a new type of sustainable urban development, and investment priorities. China's role in the world is now of a magnitude that makes its actions in the immediate future critical to how the world goes forward. This decade, 2021–2030, is of fundamental importance to human history. If society locks in dirty and high-carbon capital, it raises profound risks of irreversible damage to the world's climate. It is crucial for China to peak its emissions in the 14th Five-Year Plan (by 2025), making the transition earlier and cheaper, enhancing its international competitiveness in growing new markets and setting a strong example for the world. The benefits for China and the world as a whole could be immense.

1. Introduction

The COVID-19 pandemic has created an unprecedented threat to both public health and the global economy. In response to the crisis, the necessity of not going back to the old economic model and avoiding high carbon investments should be recognised.

The old growth model, driven by physical capital accumulation and high-carbon energy sources, is no longer viable as it has become immensely environmentally destructive and deeply socially divisive. It does not only cause severe damage to climate and biodiversity, but also make pandemics more likely, through its transformation of interactions between and among wild animals, domestic animals and humans. Further, the old economic model was accompanied by many stresses of insecurity and inequity. Investment in social and institutional capital is necessary to build trust, restore faith in effective institutions and replenish social cohesion.

There is a critical need for a path out of the global economic crisis caused by COVID-19 that is focused on investment in the sustainable economies and activities of the future. That means short-term stimulus should support post-COVID economic recovery and avoid high-carbon investments, to be aligned with the long-term development strategy and climate goals. Against the background of the COVID-19 pandemic, increasing countries are now recognising the risks posed by unmanaged climate change, which are likely to be greater and longer-lasting than those posed by the pandemic.

The global importance of China, the world's second-largest

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https://doi.org/10.1016/j.ese.2021.100130

economy, means that its immediate actions will have wide-ranging and lasting impacts on the world and its trajectory in the coming decades and over the entire century. This is due more than to the country's size — its influence also comes from its technologies, strategies and leadership in coming out of the COVID-19 crisis [1]. China's consumption and investment demand could play an important role in the global recovery from COVID-19. And its actions in the coming years on climate change will influence other countries' commitments to reduce their emissions. If China heads back towards the old polluting and wasteful practices of the past, it would send a very backward-looking signal to other countries. Both China and the rest of the world would be deeply damaged for the foreseeable future.

As China creates its next 14th Five Year Plan, for the years 2021–25, its actions in the aftermath of the pandemic are critical to how the world moves forward. In September 2020, President Xi Jinping announced at the United Nations General Assembly that China will aim for carbon neutrality by 2060. This significant pledge shows China's long-term ambitions and priorities, and that China is willing to step up efforts in the global fight against climate change. However, it requires ratcheting up ambition on its near-term climate policy and linking the long-term climate goals with its short-to medium-term social-economic priorities, which are largely guided by the 14th Five Year Plan.

China's 14th Five-Year Plan and the post-pandemic recovery present an important opportunity to accelerate the transformation to a carbon-neutral economy. Against this background, this paper discusses major action areas for China's 14th Five-Year Plan, focusing on three aspects: the energy transition, a new type of sustainable urban development and investment priorities.

The remainder of this paper is organised as follows. In Section 2 we put forward suggestions for key strategies for the 14th Five-Year Plan, among which energy transition, urbanisation and investment are particularly crucial. We address these in more detail in subsequent sections: Section 3 considers the energy transition and early peaking of carbon emissions; in Section 4 we examine a new type of urbanisation and its role in low-carbon economic growth; and Section 5 considers investment priorities across the four types of capital, in particular technological infrastructure. Section 6 concludes.

2. Key priorities for China's 14th Five-Year Plan after COVID-19

The transition to sustainable growth is the only credible economic strategy for China. It will involve the structural transformation of industry towards higher skills and technology, with less material input; new technologies, putting to work the extraordinary advances of recent times; re-designing energy and transport systems; much stronger investment in natural capital and infrastructure than in the past; investment in human capital, through both education and health; and strengthening community and social institutions. This transition can establish China's competitive leadership in the global economy and set an example to the world on sustainable recovery and transformational growth following the COVID-19 crisis. The major priorities for action in the 14th Five-Year Plan are described as follows.

2.1. Early peaking of emissions

China made historic commitments during 2020 on climate action. In September, President Xi pledged that China would reach carbon neutrality, or net-zero emissions, by 2060. In December, he further announced that China's carbon dioxide emissions would peak before 2030, rather than by 2030. This means that China's emissions will need to decline from a peak to net-zero in about 30 years, a hugely ambitious target given that many rich countries are seeking to achieve net-zero more than 40 years after their emissions peaked.

The 14th Five-Year Plan will be a crucial period for China if it is to achieve the 2060 target. If China can peak its carbon dioxide emissions by the end of the 14th Five-Year Plan period, it would be in a better position to reach the carbon neutrality target by 2060, not least because it would likely mean it seeks to reach net-zero from a lower peak and over a longer timescale. Early peaking could be achieved by accelerating many of the actions and investments that China will be making in order to make the transition to sustainable growth. This acceleration during the period of the 14th Five-Year Plan would allow China to enjoy the economic benefits of these actions and investments earlier.

2.2. Clean energy transition

Cutting coal consumption and replacing it with cleaner energy sources have been important priorities in successive Plans since the 11th Five-Year Plan (2006–2010). President Xi has recently reiterated the importance of green development and the pressing need for a clean energy transition. China has also committed to greening its major multi-country infrastructure and development project, the Belt and Road Initiative. That should mean China will soon stop investing in coal-fired power plants domestically and in other countries.

If China accelerates the transition to cleaner energy, as part of a strategy for peaking greenhouse gas emissions during the 14th Five-Year Plan (i.e. by 2025), it could change the world's commitment to the environment and could contribute greatly to the success of both the 15th session of the Conference of the Parties to the Convention on Biological Diversity (CBD COP15) and the 26th session of the Conference of Parties to the United Nations Framework Convention on Climate Change (COP26), both of which are due to take place in 2021.

2.3. Geographical rebalancing and the new urbanisation

In response to the slowdown of globalisation and the economic impacts of the COVID-19 pandemic, President Xi emphasised a “dual circulation” strategy as a major shift away from the export-led growth of the last two decades. China now emphasises deepening the supply-side structural reform and innovative capabilities of the economy and increasing the reliance on the domestic economy (including domestic supply chains, indigenous innovation and domestic demand) while maintaining close engagement with the global economy.

China's growth and wealth creation, which have been centred on large cities, must be adjusted to support people living in smaller towns and peripheral regions. Urbanisation — as a key driver of domestic demand — will have to play a central role in the rebalancing towards greater reliance on the domestic economy. This rebalancing strategy can be enhanced through a shift from the export-oriented megacity ‘hubs’ to smaller, well-contained ‘clean, compact and connected’ (CCC) cities in the interior [1]. By moving activities into the interior, China will generate employment and ensure a cleaner and healthier environment. The post-pandemic stimulus plans represent great opportunities to promote strong, dynamic and sustainable urban transitions.

2.4. Investment in technology infrastructure

China's blueprint for the infrastructure development initiative could enable new drivers of economic growth. This initiative

focuses on three aspects: information-based infrastructure, converged infrastructure for new digital technologies, and innovative R&D infrastructure. Some new technologies, such as hydrogen electrolysis, offer potentially huge export opportunities for China. The implementation of digital technologies across economic and social sectors can improve energy efficiency and promote a sustainable transition through systems innovations.

China's economic recovery from COVID-19 should follow a different route compared with responses to past crises. It should avoid investments in traditional infrastructures, such as coal-fired power plants and roads, and instead should focus on the technologies of the 21st century. Tilting backwards would lead to stranded assets and stranded jobs.

2.5. Local public finances and sub-national own-source revenues

Local governments in China were facing a debt spiral before the pandemic. Strong fiscal measures and reforms are needed to ensure that the stimulus and investment packages in response to the pandemic can embody and incentivise sustainability in finances, and do not lock in existing and environmentally damaging production patterns.

The central government should clarify the key responsibilities of different levels of government, including innovation zones, metropolitan areas and clean, compact and connected cities. At the same time, appropriate own-tax handles (utilising the State Taxation Administration) are critical for accountability, together with better-defined financing for central objectives. There should be an improvement in the flow of information about where money is spent and the outcomes of public spending and investment design. The Government should seize the current opportunity for fiscal reforms and lay the foundation for future growth and stability, as it did in the early 1990s.

2.6. Enhancing governance to deliver strong, sustainable and inclusive growth

Administrative reform, both regionally and across government, will be required to realise the new form of sustainable growth and development. As part of the necessary reform, clarity is needed on local spending assignments, as well as on financing mechanisms and the management of associated risks and liabilities.

High-quality strategies for sustainable and resilient investment and innovation must be coherently managed across the whole of government. That means there needs to be a special role for the National Development and Reform Commission (NDRC) and the Ministry of Finance, whose responsibilities cover the whole economy, to ensure the consistency of investment strategies with sustainable growth. If sustainability is embodied in all investments, it can really drive growth. It is a positive story and goes much further than simply objecting to damaging activities, however necessary that may be.

2.7. Encouraging positive behavioural changes after the COVID-19 pandemic

The COVID-19 crisis has generated creativity and the acceleration of change. Some of the positive behavioural changes should be encouraged, expanded and promoted after the pandemic. These include better use of urban space; investments in public transport capacity to offer an attractive substitute for private cars, and to avoid sprawl and the hollowing out of cities; reclaiming streets for pedestrians and cyclists; and reduction on local air pollution. Such improvements in the quality of city life can increase well-being and enhance future growth by creating an attractive environment for high-skill workers.

The pandemic has helped to create markets for new technologies and to spawn new business models, such as remote offices, online education, unmanned automated services, and fresh food e-commerce. Particular attention should be paid to strengthening connected technologies and virtualisation through high-speed broadband; technologies for virtual learning, healthcare and security; real-time supply chain management; and improved residential energy efficiency to decrease the costs of working from home. A permanent shift in business travel patterns should also be anticipated. And we should not forget the sense of community and neighbourliness that has emerged strongly.

3. Energy transition for ensuring sustainable development

China's 2060 carbon neutrality commitment will play an important role in accelerating its low-carbon energy transition to rapidly reduce economy-wide emissions towards net-zero. Central to any pathway to achieve this goal must be that China begins to generate most of its electricity from non-fossil-fuel sources, and then quickly expand the use of this clean power wherever possible [2]. Crucially, this means accelerating the transition to cleaner energy and a radical turn away from coal, replacing it with clean heating sources, reducing industrial coal consumption through restructuring and technological progress, and ending the construction of coal-fired plants while promoting renewable energy generation instead. A recent study by Tsinghua University suggests China would need to transform its energy mix dramatically by boosting its share of non-fossil fuel energy to 84% and completely phasing out coal-fired plants by 2060 [3]. This calls into question the future of dozens of power plants currently under construction or planned, which either will lock in decades of pollution and high greenhouse gas emissions or will have to become stranded assets.

In many cases, the pressure to continue with coal mining comes from local governments that are dependent on royalties from mining operations. Tackling this dependency involves the joint determination of alternative tax assignments for local governments, and tax and pricing policies. These reforms should be undertaken in tandem with decisions to stop building more coal-fired plants, while promoting renewable energy generation. There is also an urgent need to support affected coal communities and ensure a 'just transition' for workers. That should include transparent and comprehensive policies on compensation and medical support, as well as an occupational retraining programme to help affected coal workers build a future. Jobs in coal are jobs of the past and as such are insecure. Workers in China, as in countries across the world, would benefit from their government pursuing the employment opportunities of the 21st rather than the 20th century.

National energy security, along with the ultimate emissions reduction target, is of utmost priority for China. China's Two Sessions ("*Lianghui*") took place in May 2020, putting energy security at the top of sector priorities, to be achieved primarily by developing production, supply, storage and sales of all energy sources, including coal, renewables, oil, natural gas, and electricity. There was also a focus on the need to develop reserve systems — to respond to energy sector shocks and reduce reliance on imported energy — and for better regulation of energy company operations. However, the re-emphasis on energy security has led to concerns that energy industry lobbies may seek additional support in the name of 'promoting energy security', and creating a fundamental role for coal in ensuring future power supplies [4].

Ever since China became a net importer of crude oil in the 1990s, its reliance on oil supplies has surged. China currently imports around 70% of its oil, despite the Government's efforts to cap this at around 62% of supply [5]. This proportion is expected to grow above

80% by 2030 [6]. Oil insecurity in China has long been recognised, and is often associated with geopolitical challenges.

China has been a net importer of natural gas since 2007 and currently imports supply 45% of consumption [5]. As with oil, there has also been much debate over what level of overall dependence on natural gas imports is acceptable. Given that natural gas is a cleaner energy source than coal, it has been playing a growing role in China's energy mix in recent years under the coal-to-gas switching programme. This has exposed the supply-side shortage of gas, especially at times of peak demand in the winter months. As most natural gas supplies provide residential heating in China, shortages could lead to serious consequences – in winter 2017, residential homes in northern China were left in the cold due to gas supply shortages. Underground natural gas storage is an effective way to achieve peak load regulation. However, China's underground gas storage development is still at a relatively early stage, and there are far from enough gas storage facilities. In 2018, the capacity of working gas – defined as the amount of natural gas stored underground that can be withdrawn for use – only covered 3.4% of annual natural gas consumption in China, far below the international average of 10–12% [7].

Investment in non-fossil fuel technologies is the key driver for China to transform its energy sector to zero-carbon. These will include lower-cost solar photovoltaic (PV) and wind power to enable greater penetration, supported by commercialised energy storage technologies. An effective energy transition also means promoting the decarbonisation of the economy through greater electrification, for example, switching from fossil-fuelled vehicles to electric ones. Compared with fossil fuels, renewable energy offers much greater security for China. However, renewables are often discussed in China as an inherent part of the power system, with emphasis placed on their contribution to employment creation rather than to energy security. In fact, renewable energy is an important part of China's energy resource endowment and a feasible solution for ensuring energy supply security while also meeting its environmental and climate performance targets.

Renewables, including solar PV and wind power, have become highly competitive economically. In addition, energy storage costs are falling, and network management is improving. These technical advances are likely to continue. A recent study by Ref. [8] suggests that if the cost trends for renewables continue, 62% of China's electricity could come from non-fossil sources by 2030, at a cost that is 11% lower than would be achieved through the current business-as-usual approach.

The management of the grid is increasingly a major barrier to the large-scale penetration of renewables in China. The running of the current grid system implies there is a limit for the share of renewables that can be absorbed by the grid: when electricity generation from renewables increases, balancing mechanisms such as storage (e.g. batteries, pump storage or hydrogen) or generation from other sources, including coal-fired power, will also need to grow, to provide the necessary flexibility to respond to the intermittency of renewable supply. This is arguably why there has been an increase in generation capacity from coal-fired plants in parallel with growing supply from renewables to meet rising electricity demand.

However, the addition of more coal capacity is far from being the only way to manage the intermittency of renewables. For example, demand-side response measures – from participants including industrial users, private users and energy storage capacities – could offer a better solution for managing peaks in demand. This can help to create a balance between demand and supply and enable flexible utilisation of electricity, which can be used to provide extra capacity for peak periods, while reducing the need to curtail renewable energy in cases of local oversupply. The development of digital technologies allows technical support for realising the potential of demand-side responses by offering greater control and optimisation of supply. Besides demand-side response, the existing coal-fired plants can play a role in providing flexibility through retrofitting without the need to build new ones. In addition, the new energy vehicles (NEV) industry in China has undergone rapid development in recent years as part of the Government's strategy to address the challenges of energy security and emissions. As more and more NEVs are being used, there will be a huge capacity from car batteries and smart charging piles available to help create flexible balancing for electricity load variation.

A modern, smarter grid system is urgently needed, not only through the upgrade of the grid infrastructure but also by providing the technical guidance and standards that determine how the grid runs. At the end of 2019, China released a new standard and technical guidance, the 'Code on Security and Stability for Power System (GB38755-2019)'. It came into force in July 2020, replacing the old standard (DL755-2001), which the grid had been following for two decades.[1] Both national guidance and local implementation are greatly needed for the management of the grid, enabling more advanced technologies and eliminating the institutional barrier to large-scale integration of renewables into the electricity market.

The electricity market itself presents another barrier. Due to the incomplete forward electricity market, China's generation dispatch is primarily determined by the annual generation planning carried out by provincial governments. They set out long-term unit commitment plans specifying for each generation unit whether it serves as the base load generator or marginal generator. Generators of the same type (e.g. coal-fired, wind, solar) are usually allocated about the same annual utilisation hours in order to guarantee an equitable opportunity for cost recovery. However, this 'fair dispatch' rule is facing an increasing challenge with the fast rate of progress of low-cost renewable sources and rapid digital transformation accelerating change in power systems. The Chinese government should push ahead with market-based economic dispatch in a way that the generation unit with the lowest costs has priority for meeting electricity demand. This would reduce the total costs of serving consumers, and improve renewable integration by taking advantage of the near-zero marginal cost of wind and solar generators.

4. New urbanisation as a major driver of low-carbon economic growth

In parallel with industrialisation, urbanisation has been the central driver of China's rapid economic growth in recent decades. China's phenomenal export-led growth performance has been based on the development of coastal 'hubs', leading to a transformation of the whole country from a traditional agrarian society into one that is modern and urban [9]. Urbanisation has brought new jobs, enhanced livelihoods, and enabled the modernisation of education and healthcare for most of the population.

But cities are now facing great challenges, including environmental pollution due to a concentration of industrial production; income and wealth inequality within and between different regions; traffic congestion; and shortcomings in education, healthcare and social support, as more people are moving to cities and the population ages. This is partly a result of China's prior emphasis on developing the coastal megacities, and there is an urgent need to transform its established urban areas and steer urbanisation towards sustainable hubs in its interior, which have yet to benefit from the degree of wealth creation experienced in urban regions

[1] http://www.xinhuanet.com/power/2020-01/08/c_1210429744.htm.

along the coast [10].

The old drivers of urbanisation are losing momentum, as the industrialisation model of polluting, energy-intensive and high-carbon growth can no longer meet the requirements for building a strong, sustainable and resilient economy [11]. In the past, access to raw materials or ports was important, but in a maturing economy, skilled workers are likely to matter more for a city's prosperity [12].

The growth benefits experienced by Chinese cities have resulted from agglomeration economies where the clustering of people generates higher productivity and higher wages [13]. A mix of specialisation and diversity drives a fertile environment for innovation in ideas, technologies and processes, while also generating pools of skilled labour and infrastructure for more efficient use of resources [14]. But COVID-19 and the threat of other pandemics could undermine these gains by encouraging policies to limit direct social and economic interaction.

The COVID-19 pandemic has also raised questions around modern urban design. High-rise and densely populated buildings may induce conditions favourable for disease transmission through air-conditioning and ventilation systems, sewage systems, high-use common spaces, and, especially, lifts/elevators. However, this does not necessarily mean that the transmission and impacts of COVID-19 are worse in densely populated metropolitan areas, as these areas may offer better access to healthcare facilities and allow for more effective implementation of social distancing practices than less densely populated areas [15]. Most importantly, proper urban planning and management are needed to ensure densely-populated areas are well located and coordinated with services.[2] There are significant policy and investment challenges in combining the many advantages of high-density living and working in functioning, efficient and attractive cities, with the successful management of the risks of infectious diseases.

While China has taken serious action in recent years to address environmental and climate challenges, the rapid development of new technologies and the lessons from the pandemic add fresh urgency to the need to adopt sustainable urban development. This involves accelerating structural measures for a 'rebalancing' that shifts activities from coastal metropolitan areas to clean, compact and connected (CCC) cities in the interior, while also transforming already developed areas [1]. This rebalancing strategy, in line with the new 'Go West' development plan announced during the 2020 National People's Congress (NPC) [18], can facilitate a transition from exports to domestic consumption, along with a higher-tech, more service-orientated and cleaner economy to accelerate the realisation of an 'eco-civilisation'.

It is easier to design clean and efficient buildings and infrastructure in more manageable county-sized sub-jurisdictions and CCC cities than in large conurbations. Better urban design and development also means reducing fossil-fuel use, water use and waste production through greater adoption of renewables, recycling and efficiency in public infrastructure. Congestion can be cut in cities and regional integration can be increased by investments in green mobility systems (e.g. NEVs), public transport and improvements in links between cities. Functionally and socially mixed neighbourhoods with accessible green spaces, comfortable, affordable, climate-smart housing for all, and efficient public transport networks could both protect natural capital and provide a basis for higher quality, stronger and more sustainable economic growth.

Urban areas consume 80% of energy worldwide, with buildings accounting for almost half the total [11]. This means it is important to implement best practice in energy and resource conservation in new buildings. The careful planning of compact, connected, and coordinated use of land in cities can unlock the power of urban areas to deliver clean economic development and avoid sprawl and the hollowing out of city centres. With many existing buildings in China's cities likely to be operational for decades to come, a priority area for investment, therefore, should be retrofitted to improve energy efficiency in both electricity and heating.

Investment in urban trees and woodland promotes outdoor recreation, with positive effects on physical and mental health, reducing burdens on health systems and cutting the number of working days missed, while increasing the returns to residential investment. Trees also help absorb harmful particulate pollution, lower carbon emissions, increase water retention, and provide cooling and shading services. COVID-19 has highlighted the urgent need to strengthen the quality and resilience of natural assets in cities and beyond.

Technological innovation should be a major driver for both creating sustainable growth and tackling climate change. Digital technologies should be incorporated more rapidly into buildings. For example, upgrading existing electricity meters to smart displays can help optimise energy utilisation patterns and promote energy saving. The use of digital technologies connected with related IT infrastructure, including 5G stations, big data centres, AI and the Industrial Internet of Things, can effectively promote massive energy efficiency improvements in all the major sectors of manufacturing and services. Integrated technological systems, including high-speed trains, inter-city transit, and energy-efficient buildings combined with renewable energy sources, NEVs, charging stations and smart grids, can help put China on a sustainable growth path, while accelerating the transition towards a low-carbon economy.

Construction of Xiong'an New Area ("雄安新区")[3] is a potential model of new urban development for cities in the interior, which is transforming the 1770-sq-km area in China's Hebei province into a green and innovative city of the future. With intercity railways and express lines linking Xiong'an New Area with Beijing and Tianjin, the area is designed to take over non-capital functions from Beijing and facilitate the Beijing-Tianjin-Hebei (BTH) integration. It is on track to become a green urban hub with harmonious human-environment interaction, as great efforts have been made on afforestation, ecological restoration and sewage treatment.[4] Committed to 100% green power supply and high electrification level, Xiong'an New Area has been exploring clean and diversified energy supply systems integrated with renewables and supported by energy storage and digital technologies. In September 2021, the integrated energy services demonstration project led by a subsidiary of the State Grid Corporation of China, located in the Xiong'an high-speed railway station, was announced by the Ministry of Ecology and Environment (MEE) as a typical case of green and low-carbon development.[5]

It is worth noting that moderating or reversing the current migratory trends towards the existing coastal megacities requires investment to enhance the attractiveness of remaining in the interior regions. This investment should not only be in physical capital but also in human and social capital and services, particularly to ensure that health and education are more evenly distributed within CCC cities and across the country. The tremendous technological advances made by China through e-commerce,

[2] For more context on the ongoing debate around whether density contributes to the current pandemic transmission, see, for example [16], and [17].

[3] https://special.caixin.com/event_0401_1/.

[4] http://www.xinhuanet.com/english/2021-04/01/c_139852880.htm.

[5] http://www.xiongan.gov.cn/2021-09/17/c_1211373879.htm.

information technology and big data could also benefit the evolution of interior CCC cities, persuading private firms to relocate closer to population centres and bring supply chains nearer to where demand is generated. The provision of basic services to attract workers and households will be critical.

A focus on CCC cities could also facilitate a more radical sustainable urban transformation of the existing megacities. This would include measures to limit congestion by improving facilities for cycling and pedestrians, retrofitting buildings to make them more energy-efficient and climate-resilient, and upgrading fossil-fuel-based infrastructure to become low-carbon. It would also mean fiscal transformation and improved governance with monitoring and accountability at its core to enable these changes in megacities. The transformation of the existing megacities can also be promoted by the creation of high-tech innovation zones, with the development of IT infrastructure, high-skill research centres and top universities and financial sectors, in the drive to sustainable and strong growth (for example, the Yangtze River Delta and Greater Bay Area programmes).

China needs to continue to invest in urban infrastructure as part of its rebalancing towards interior CCC cities, as well as the transformation of the megacities in light of COVID-19. The choices made in transport, infrastructure, buildings and industry, in cities today as they continue to grow will determine, via the technology and way of life they engender, whether humankind can both manage climate change and capture the benefits of low-carbon growth over the coming decades. This investment in a new type of urbanisation could be a major driver of, and requirement for, sustainable, resilient and inclusive economic growth.

5. Investment for ensuring a post-pandemic recovery and the long-term prosperity

[19] have set out a new sustainable growth strategy for China in broad terms. Within the context of that growth strategy [20], have examined the complementary nature of the four types of capital — physical, human, natural and social — and their role in China's new phase of development. Although the pandemic has changed the situation in many important ways, inside and outside China, the fundamentals of the medium-to long-term analyses of these papers have not changed: i.e. that the relevance of the old economic model with a narrow focus on physical capital has come to an end and a new, high-quality growth model driven by innovations and investment in the four types of capital is the only path to long-term prosperity. However, the short term is very different due to the health, economic and social effects caused by COVID-19, and it will be important to integrate, both in China and the world, the recovery from the pandemic with the transformation of the economy in the medium to long term [21]. This means the transition to a low- and zero-carbon world and a revolution in digital technologies.

China's recent commitment to a net-zero emissions trajectory will also be critical to its economic and environmental wellbeing in the coming years, including not only sustainable growth but also clean cities where citizens can move and breathe and ecosystems that are robust and fruitful. While physical capital has been central to China's economy over the past few decades, recently, there has been a deepening of the understanding that low-quality and polluting physical capital can damage other types of capital, leading to a form of economic development that is unsustainable.

[22] estimated that, as of 2018, the world's existing CO_2-emitting energy infrastructure has grown to US$22 trillion in economic value. By the time of its retirement, this infrastructure will have been responsible for cumulative emissions of 658 Gt of CO_2 — that is 19 times the global CO_2 emissions of 2019 — with more than half coming from the power sector. That amount could rise to 846 Gt CO_2 if all proposed power plants around the world are built. Although it accounts for less than 25% of the estimated economic value (roughly US$5 trillion), power and industry infrastructure represent more than 75% of total committed emissions (519 Gt). Tong et al. also concluded that the power and industry sectors in China represent especially prime targets for unlocking future emissions — Chinese infrastructure is associated with 46% of these sectors' global committed emissions.

This highlights the urgent need for China to stop building more coal-fired plants. Instead, it should redirect investment into low-carbon and resilient infrastructure and technologies to promote an energy transition towards more renewables and build more productive, more attractive and healthier cities.

The investment in greening the power sector is of great significance to China and to the world. It needs to include energy-saving through increasing the efficiency of electricity generation, and switching to cleaner sources, including from coal to gas but also to non-fossil fuels, to reduce emissions per unit of electricity generated. It should also invest in carbon removal technologies (e.g. carbon capture and storage [CCS]) and nature-based solutions to increase carbon sinks. As discussed in Section 4, investment in digital technologies and related IT infrastructure is critical for promoting massive energy efficiency improvements across all major sectors.

Investment in clean technologies is undoubtedly the key driver for China's shift to a strong low-carbon transition pathway. The share of non-fossil fuels in China's national energy mix rose to 15.3% in 2019, achieving its target ahead of schedule. According to the National Energy Administration (NEA), China had 204.7 GW in installed solar PV power generation capacity at the end of 2019, a significant increase on the 0.02 GW 10 years earlier; similarly, the total installed capacity of wind power generation increased from 16.1 GW in 2009 to 210.1 GW in 2019. Robust future growth in renewables is anticipated; China has become the world's largest producer of solar cells, surpassing Europe and Japan [23]. China should continue its investment in developing stronger solar PV and wind power industries and encourage more technological innovation to further enhance the international competitiveness of its products. The job creation rate of these industries is between 1.5 and three times that of traditional energy industries, according to Ref. [24].

As discussed in the previous section, investment in an improved urbanisation can deliver great benefits in terms of sustainability and resilience. It can also result in more attractive cities with functionally and socially mixed neighbourhoods, strong public services and efficient public transport networks [13]. Sustainable urban development would offer China a much more attractive future than the urban sprawl that is developing in many cities (see also [25]. Investment in integrated technological systems can boost sustainable growth by creating new jobs, while accelerating the transition towards carbon neutrality. For example, investments in the creation of a flexible electricity supply to residential and office buildings, based on a direct current (DC) distribution network, can enable their effective combination with renewable power generation, NEVs, charging stations and smart grids, and promote cross-sector decarbonisation.

The Chinese government has made clear that investing in natural capital and social capital is an important part of its strategy in the next development phase. China has already recognised how essential natural capital is through an emphasis on the framework of ‘eco-civilisation’. It has started to take action to conserve biodiversity and ecosystem services, and to fight against air, water and land pollution. Examples include: (i) the near-term clean air targets delineated in the *Three-Year Action Plan to Win the Blue-Sky Defense War* and long-term clean air targets that are in line with the WHO

air quality standard in its major cities [26]; (ii) the launch of the 'Sponge City Program' (SCP) in 2015, which aims to manage urban stormwater and is seen as a breakthrough of planning in urban water resilience and sustainability [27]; and (iii) China's soil pollution action plan initiated in 2016, which aims to bring 90% of polluted land safely into reuse by 2020 and to continue to improve soil quality with 95% of contaminated land being available for reuse by 2030 [28]. China has also introduced ambitious reforestation programmes, such as the 'Great Green Wall', to fight desertification and increase its forest cover. And, of course, it is moving to curb carbon dioxide emissions and become carbon-neutral by 2060.

China recognises the importance of social capital and cohesive society, tackling inequality and taking action to promote good governance. China has long invested, through health and education, in the human capital of its people, although there is a need for further investment, especially in rural areas.

Following through with these policies and investments would offer returns that could be very large for China. There is convincing evidence that stimulus plans can deliver both economic and climate goals. Projects that cut greenhouse gas emissions as well as stimulating economic growth can deliver higher returns from government spending, in the short and long term, than more conventional stimulus spending [29]. Many sustainable projects and programmes can be implemented quickly, are labour-intensive and create strong economic multipliers. This can foster a transition from a strong recovery from COVID-19 into sustainable, resilient and inclusive economic growth. It can also crowd long-term capacity by stimulating investment in complementary productive assets [30].

6. Closing remarks

To limit the human and economic impacts of the COVID-19 pandemic, it is crucial for governments to take visionary and decisive action to turn the crisis into an opportunity for transformation. A long-term strategic vision that supports the commitment of 'building back better' is needed to avoid reverting towards the old dirty technologies of the 20th century. Hesitation and inaction on sustainability could push the world towards catastrophic climate change.

Due to its size and growth momentum, China's role in world demand is fundamental. During the financial crisis of 2008–10, China's soaring demand boosted growth worldwide and drove a global economic recovery. Now, in contrast to recovery from previous crises, China will likely increase demand through a balanced combination of consumption and investment rather than a strong and narrow focus on infrastructure. China's leadership in the COVID-19 recovery phase is crucial for the country and the world.

There is a critical need for a path out of the current global economic crisis focused on investment in the sustainable products, technologies and activities of the future. China's future development, wellbeing and quality of life will depend critically on the four complementary types of capital. Low-carbon, resource-efficient investments will likely increase China's own competitiveness, drive innovation and enhance productivity. Pursuing the carbon neutrality goal does not mean sacrificing economic growth. In fact, the low-carbon transition can boost growth in so many aspects, including facilitating economic upgrading, creating better job opportunities, ensuring the security of energy supplies, and saving huge economic and societal costs associated with climate change and public health damage. China is implementing its 14th Five-Year Plan, for the years 2021–25, in the aftermath of the pandemic – the actions it commits to are critical to how the world moves forward and can establish China as the global leader for the 21st century. A summary of major action points is shown in Table 1.

Table 1
Summary of key action points for China's 14th Five Year Plan.

	Energy transition	New urbanisation	Investment priorities
Strategies/Goals	Move away from coal; Ensure energy supply security; Increase the penetration of renewable energy into grid utility.	Towards sustainable urban development; Reduce energy use and carbon emissions in cities; A 'rebalancing' strategy that shifts activities from coastal areas to CCC cities in the interior.	Invest in the four types of capital (physical, human, natural and social capital) for long-term prosperity; Invest in infrastructure and technologies that promote the energy transition and new urbanisation.
Barriers/Challenges	i) Local governments of coal-dependent provinces; ii) Relocation of laid-off coal workers; iii) Dependence on oil and natural gas imports; iv) Grid management; v) Electricity market.	i) Urban design issues highlighted by COVID-19; ii) energy consumption and efficiency issues; iii) migratory trends towards the existing coastal megacities.	i) Prior emphasis on physical capital; ii) China's power and industry sectors as the prime targets for unlocking future emissions; iii) Reduce emissions while promoting strong and sustainable growth.
Key action points	i) Reform on local government taxation and accountability; ii) Improve compensation policies and occupational retraining to affected coal workers; iii) Ensure security of energy supply through investing in non-fossil fuel technologies; iv) Upgrade grid infrastructure and technical standards; increase grid flexibility via various routes rather than adding more coal capacity; v) Push ahead with market-based economic dispatch.	i) Better urban planning and management; greater adoption of renewables, recycling and efficiency in public infrastructure; build climate-smart housing and efficient public transport networks; strengthen the quality and resilience of natural assets in cities; etc.; ii) Implement best practice in energy and resource conservation in new buildings; retrofit existing buildings to improve energy efficiency; careful planning of land use; incorporate digital technologies into buildings; etc.; iii) Ensure health and education services are evenly distributed; fiscal transformation in CCCs and existing megacities.	i) Integrate the recovery from the pandemic with the transformation of the economy in the medium to long term; focus on many sustainable projects that can be implemented quickly and create strong economic multipliers; ii) Invest in energy-saving, clean energy and carbon removal technologies; invest in digital technologies to promote energy efficiency improvements across all major sectors; iii) Stop building more coal-fired plants; redirect investment into low-carbon and resilient infrastructure and technologies to serve as the new driver of growth and secured jobs.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Cameron Hepburn declares financial support from the Smith School of Enterprise and the Environment, University of Oxford for the submitted work. Ye Qi declares financial support from the Foreign and Commonwealth Office of the British Government for research on climate risk analysis, through Chatham House. Nicholas Stern, Bob Ward, and Chunping Xie declare financial support from the Energy Foundation China, the Grantham Foundation for the Protection of the Environment and the London School of Economics and Political Science for the submitted work. Dimitri Zenghelis declares financial support from the Energy Foundation China for the submitted work.

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