MINISTRY OF FOREIGN AFFAIRS
OF DENMARK
Innovation Centre Denmark

CHINA'S GREEN TRANSITION

AN R&D PERSPECTIVE

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AUTHORS: THOMAS TRØST HANSEN
INNOVATION ATTACHÉ
THOHAS@UM.DK

CHRISTINA BUNDGAARD MARK
SCIENCE AND INNOVATION OFFICER
CHRBMA@UM.DK

FRONT PAGE: COLOURBOX

KAIROS FUTURE

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PREFACE

The Danish Government has put forward the ambitious goal for Denmark to reduce its greenhouse gas emissions by 70 percent compared to the 1990 level. The 70 percent target and the 2050 climate neutrality target mark the first time Denmark has stipulated targets for total Danish greenhouse gas emissions by law.

Achieving the 70 percent target by 2030 will require substantial effort and cannot be accomplished through existing technology – it requires intensifying the effort in known avenues as well as exploration of new tracks. Neither can it be accomplished by Danish researchers alone. We need to collaborate internationally and engage in meaningful research and innovation partnerships.

Chinese universities are home to some of the world's leading research environments within a broad range of green technologies, and is thus an essential partner in transitioning to a greener economy and a low-carbon society.

In the spirit of international exchange and collaboration of innovative solutions to climate challenges, Innovation Centre Denmark in Shanghai set out to explore which research areas offer the greatest potential for extended Sino-Danish collaborations.

I hope this report will be of guidance and inspiration to future knowledge collaborations on the green transition.

Thomas Trøst Hansen

Innovation Attaché
Innovation Centre Denmark in Shanghai

Introduction

The Chinese government grapples with the environmental implications of decades of unparalleled growth, rapid industrialisation and an increasingly consumptive society. To mitigate the ecological consequences in the most cost-efficient manner, the Chinese government invests heavily in green research and innovation.

The purpose of this report is twofold. It provides a general introduction to the green R&I-efforts undertaken by China, as well as a mapping of research areas that offer the greatest potential for extended Sino-Danish collaborations as seen from a Danish perspective.

The analysis follows four steps. Below, the framework for a green transition in China is described in terms of the political context, including targets and key actors. This is followed by a brief account of methodological considerations for selecting 11 focus areas of specific importance. The 11 focus areas are then assessed in terms of impact, size, central actors and supporting policies.

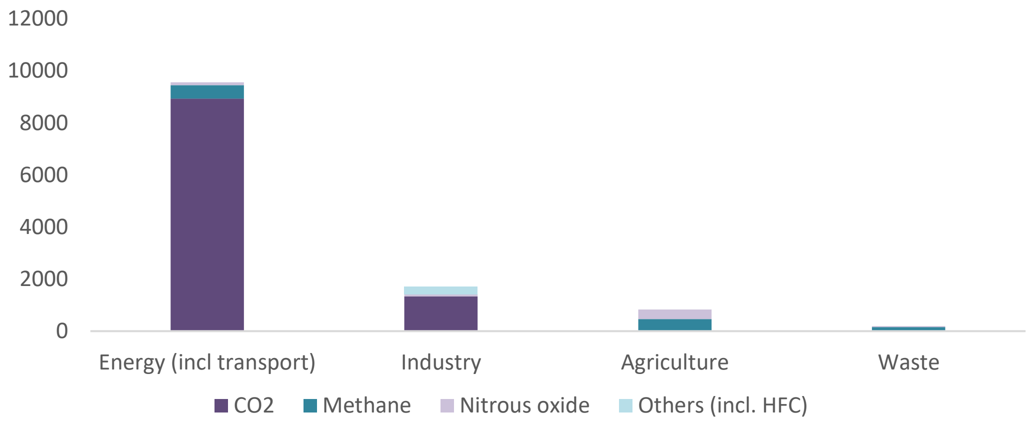
The report concludes by highlighting key insights and underlining the green research areas in which Chinese researchers are at the forefront and can be beneficial partners for Denmark.

1. Chinese climate policy: political targets and organisation

As the world's largest greenhouse gas (GHG) emitter, China accounts for approximately 27 percent of global GHG emissions. A few years ago, China showed hopeful signs of lowering CO_2 emissions. However, discouragingly, increased fossil fuel consumption drove an estimated 2.3 percent increase in Chinese CO_2 emissions in 2018, and 4 percent in the first half of 2019, thus marking a third year of growth after emissions had levelled out between 2014 and 2016.

The energy sector, including transport and industry, accounts for about 84 percent of China's total GHG emissions. Sixteen percent of China's GHG emissions come from greenhouse gases distinct from CO2: methane, nitrous oxide and hydrofluorocarbons (HFC), mainly from agriculture, wastewater treatment and waste management.

Figure 1: Emission of GHG in China (2014), MT CO2 Eq., *Source: IPCC*



The Chinese government still refers to their status as a developing country and maintains that its abilities and capacities to reduce emissions are comparatively lower than developed countries. However, it is an essential ambition of the Chinese government to both mitigate climate change and secure continued economic development. Environmental targets are embedded within national and international policy frameworks, which underscores the fact that the country is no longer merely concerned with the pace of growth, but also with the quality of growth.

Two overarching policy frameworks define China's climate targets: the Paris Agreement and the national Five-Year-Plans. China ratified the Paris Agreement and submitted its Nationally Determined Contributions (NDC) to the UNFCCC in 2016, announcing its intentions to take the following actions by 2030:

- Peak CO_2 emissions by 2030, or earlier if possible;
- Increase the share of non-fossil energy sources in the total primary energy supply to around 20% by 2030;
- Lower the carbon intensity of GDP by 60%, to 65% below 2005 levels by 2030;
- Increase the forest stock volume by around 4.5 billion cubic metres, compared to 2005 levels.[i]

By the end of 2020, all countries bound by the Paris Agreement are required to renew their NDCs. Of additional importance, 2020 is also characterised by the preparation of the 14th Five Year-Plan (2021–2025). The Chinese Five-Year-Plans are important policy frameworks that set the strategic and economic direction for Chinese society across all policy areas. The current Five-Year-Plan (2015–2020) includes several green targets, including:

- An 18 percent reduction in carbon-intensity from 2015 levels;
- Calls for controlling emissions from energy-intensive industries like power and steel;
- Building a unified national carbon emissions trading market;
- Implementing emissions reporting and verification for key industries;
- Establishing a green finance system.[ii]

The COVID-19 crisis and its consequential economic downturn has caused uncertainty about the green ambitions to be expected in the forthcoming Five Year-Plan.

Since 2018, the Chinese Ministry of Ecology and Environment (MEE) has been responsible for developing climate policy. However, many other ministries make decisions that affect emissions. The National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) are responsible for the energy sector, the Ministry of Industry and Information Technology (MIIT) for industry; the Ministry of Agriculture and Rural Affairs (MOA) for agriculture; the Ministry of Housing, Urban and Rural Development (MoHURD) for areas related to construction and energy consumption in buildings. Similarly, the Ministry of Science and Technology (MoST) holds the overarching responsibility for R&I policy, including areas important to the green transition.

The key national ministries are very important in China, but so are the provincial and local levels of government. China is a unitary state in which the central government makes political decisions and frameworks, and delegates the responsibility of implementation to subordinate levels of government. Energy, environment and restoration projects typically follow a pilot project format, where the central government outsources environmental programs to a number of pilot provinces, who then regularly report to the government. If needed, the project is moderated, and if successfully accomplished, the local model is implemented in the remainder of the country as best practice.

The environmental performance of sub-national authorities is key to China's environmental performance.[iii] The central government has broadened the performance evaluation parameters for local government officials from focusing solely on financial growth, social stability and welfare, to also include energy efficiency targets. The integration of environmental criteria in the assessment of career prospects and internal party progression of senior officials provides a basis for strengthening the oversight of sub-national governments' progress regarding green growth, while simultaneously becoming increasingly important for internal competition and individual party advancement.

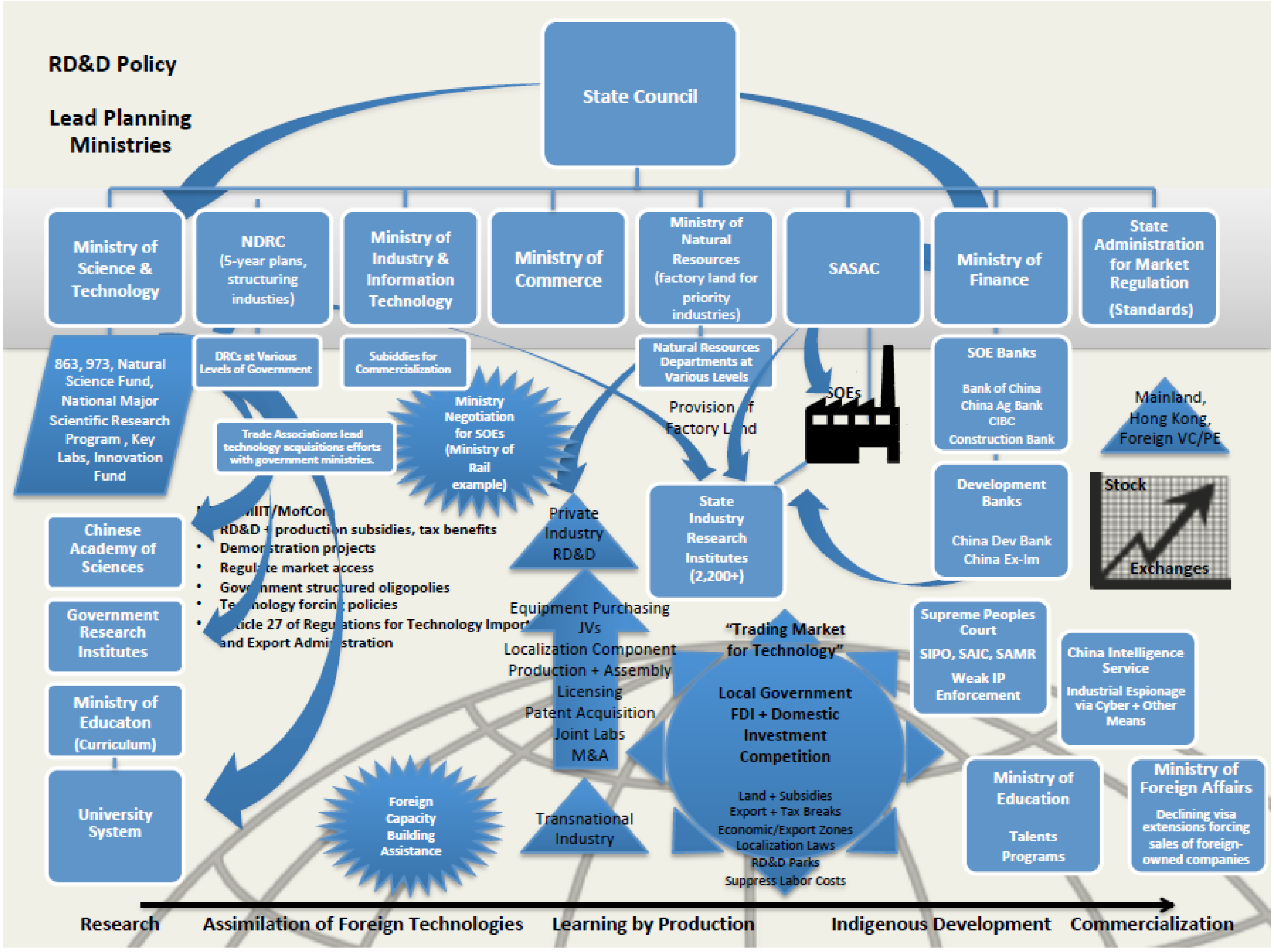
2. Green research & development

China's green ambitions are mirrored in key policies regarding science, technology and industry. Launched in 2015 by the Ministry of Industry and Information Technology (MIIT), the Made in China 2025 plan serves as a roadmap for ensuring China the status of a leading technological superpower. The ambition is to pursue an innovation-driven and talent-based approach that, within ten core industries, places quality first; two of which are energy equipment and new energy vehicles.[iv] After years of prioritising applied and experimental science[v] with the objective of amending existing products and innovations as a means for economic development, the Chinese government today aims to use basic science to move Chinese manufacturing up the value-added chain, re-establish China as a global centre of innovation and technology, and to ensure long-term productivity. The Chinese government plans to increase R&D spending to 2.5% of GDP by 2020.[vi]

Regarding the green transition more specifically, the Ministry of Science and Technology (MOST) published the *National Scientific and Technological Actions on Climate Change During the 13th Five-Year-Plan Period* in 2017.[vii] The plan emphasises the importance of excelling within a number of research areas, including forecasting and simulation models, data management platforms and carbon capture.

However, none of the plans outline specific initiatives or funding sources. Rather, these policies are broad frameworks that set the direction for a domain of inscrutable initiatives implemented across a broad range of actors, including central, provincial and local governments as well as public institutions, State-Owned Enterprises (SOEs) and private actors. Figure 2[viii] illustrates the complex landscape of R&D policy-making in China.

Figure 2: The structure of R&D policy-making in China.
Source: Mapping China's climate and energy policies, UK govt., Dec. 2018



3. Key research areas of Denmark's green transition

The policy landscape for R&I and climate policy outlined above is complex and does not in itself provide a concrete starting point for identifying the most promising partners and areas as seen from a Danish perspective. Rather, in order to provide tangible opportunities for collaboration, the report at hand focuses on research areas that are essential for the green transition of Denmark[ix], and explores how China performs within these. Eleven research areas have been identified based on analyses undertaken by the Innovation Fund Denmark and the Danish Council on Climate Change:

- Alternative cement;
- Biochar;
- Data, Artificial Intelligence (AI), Internet of Things (IoT) in the context of smart buildings and cities;
- Energy grid flexibility;
- Power-to-X;
- Green maritime technologies;
- Wind energy;
- Carbon capture and storage;
- Carbon capture and utilisation;
- Electric vehicles;
- Solar energy.

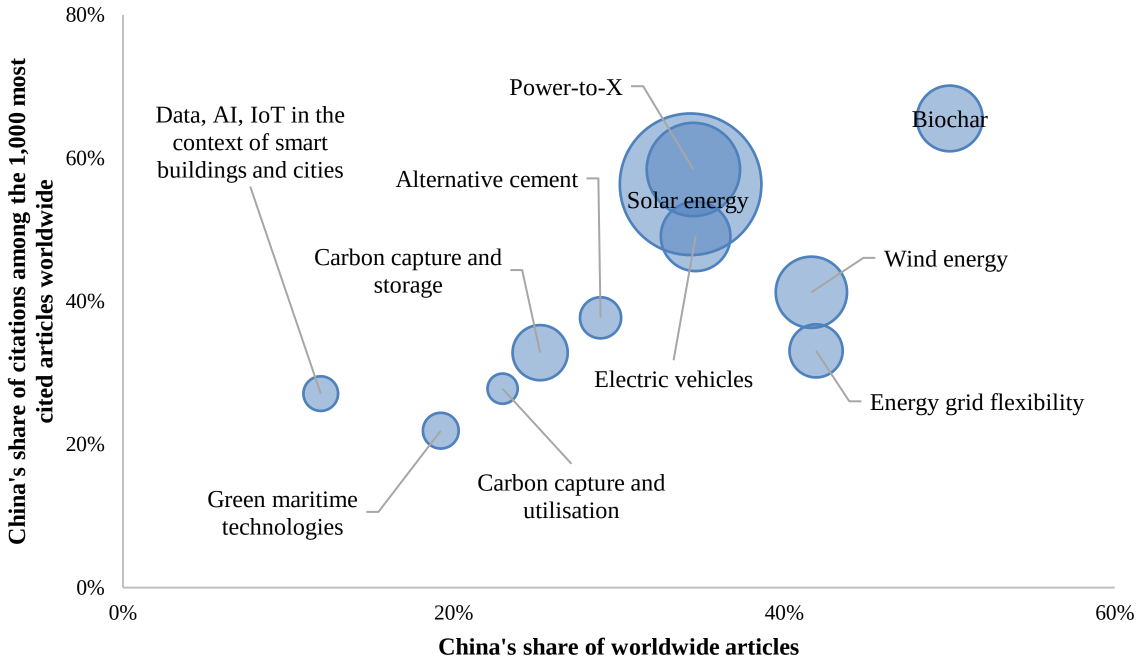
Below, the research areas will be analysed based on desk research and bibliometric analyses of 56,488 publications from Web of Science that fulfil the following criteria:

- A minimum of one China-based researcher among the authors;
- Published between January 2017 and April 2020;
- Related to the 11 research areas listed above through a series of keywords.

4. Chinese research performance in international comparison

As reflected in Figure 3, a significant share of the world's research is conducted with contributions from Chinese researchers. The area in which China demonstrates the strongest performance is *biochar*, where 50 percent of worldwide publications have a minimum of one Chinese author. Moreover, these articles represent 66 percent of global citations. Additional areas of strength include *power-to-X, solar energy*, *electric vehicles* and *wind energy*.

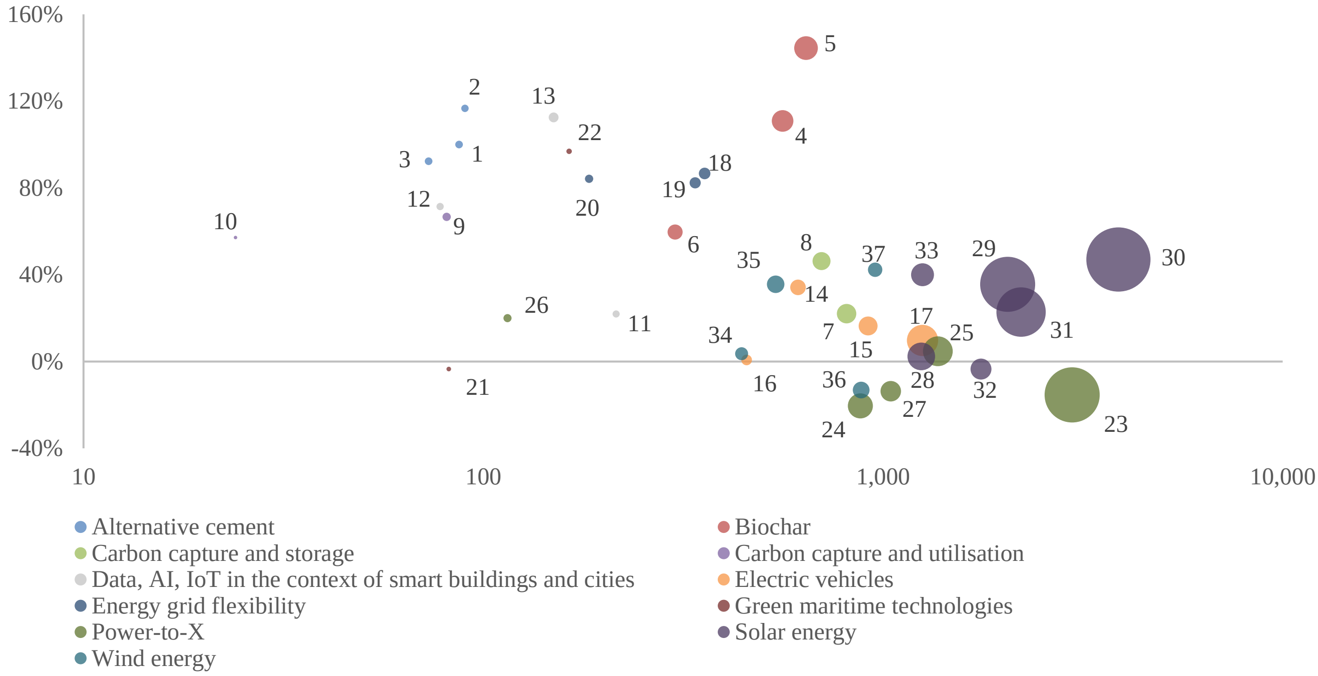
Figure 3: Activity of Chinese researchers and their performance in an international comparison within the 11 research areas. Bubble size represents the numbers of Chinese researchers active in each area, while the axes show Chinese researchers' shares of articles published worldwide in each field in total, as well as their share of citations among the 1,000 most cited articles. *Source: Web of Science, Jan 2017–Apr 2020*



Through statistical topic modelling of the articles, i.e. clustering of words based on co-occurrence in article title, abstract and keywords, 37 distinct topics emerge. These have been interpreted, labelled and quantified in terms of their volume, growth and citations of associated articles (see Figure 4). Four of the five largest topics appear in the *solar energy* area, reflecting its position as the largest focus area. Fuel cell technologies (a sub-area of power-to-X) also constitute one of the largest topics. Additional related areas include *electrocatalysis & oxygen reduction reaction* (primarily in the context of fuel cells) and *microbial fuel cells*. Other power-to-X topics, with *power-to-gas* being the most notable, are considerably smaller.

The fastest-growing topics include *biochar*, under which *soil & heavy metal remediation* and *adsorption behaviour & mechanism* stand out, whereas *microstructure & physical properties* are most noticeable in the area of alternative cement. The third fastest growing topic is *Internet of Things*, here part of a focus area within the smart building and smart city context.[x]

Figure 4: Number and growth rate of published articles in relation to specific topics within the 11 research areas. Bubble sizes represent the total number of citations of articles associated with each topic. *Source: Web of Science, Jan. 2017–April 2020.*



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No.	Topic	Focus area	No.	Topic	Focus area
1	Fly ash as alternative cementitious material	Alternative cement	20	Microgrids	Energy grid flexibility
2	Microstructure & physical properties	Alternative cement	21	Engine and fuel consumption	Green maritime technologies
3	Recycled cement	Alternative cement	22	Modelling & optimisation	Green maritime technologies
4	Adsorption behaviour & mechanism	Biochar	23	Electrocatalysis & oxygen reduction reaction	Power-to-X
5	Soil & heavy metal remediation	Biochar	24	Exchange membranes for fuel cells	Power-to-X
6	Pyrolysis process & conditions	Biochar	25	Microbial fuel cells	Power-to-X
7	Ecosystem solutions for CCS	Carbon capture and storage	26	Power-to-gas	Power-to-X
8	Technological solutions for CCS	Carbon capture and storage	27	Solid oxide fuel cells	Power-to-X
9	Catalysts for CCU	Carbon capture and utilisation	28	Dye-sensitised & quantum dot sensitised solar cells	Solar energy
10	Microalgae	Carbon capture and utilisation	29	Organic solar cells	Solar energy
11	Building information modelling	Data, AI, IoT in the context of smart buildings and cities	30	Perovskite solar cells	Solar energy
12	Computing solutions (cloud, edge, fog)	Data, AI, IoT in the context of smart buildings and cities	31	Photocatalysis & photoelectrochemical performance	Solar energy
13	Internet of things	Data, AI, IoT in the context of smart buildings and cities	32	Photovoltaic systems	Solar energy
14	Business & policy aspects	Electric vehicles	33	Solar thermal power systems	Solar energy
15	Electric vehicle charging	Electric vehicles	34	Fault diagnosis	Wind energy
16	Electric vehicle control systems	Electric vehicles	35	Prediction and forecasting	Wind energy
17	Lithium ion batteries for electric vehicles	Electric vehicles	36	Wind power generation & integration	Wind energy
18	Demand response & real time pricing	Energy grid flexibility	37	Wind turbines	Wind energy
19	Distributed power generation & control	Energy grid flexibility			

5. Main funding sources

The National Natural Science Foundation of China (NSFC) is the biggest funding source for Chinese researchers. More than half of the publications included in the study – about 30,000 – list the NSFC as their source of funding. The foundation deems basic research and identification as well as fostering of scientific talents their core responsibilities. While the NSFC dominates as the source of funding in all of the 11 research areas, other sources of funding are also of importance in some areas fields (Figure 5).

Another significant funding scheme is the National Key R&D Program. Its objective is to support R&D in a wide range of fields of strategic importance, including the environment. The National Key R&D Program is somewhat important as a source of funding in the areas of *energy grid flexibility* and *biochar*.[xi]

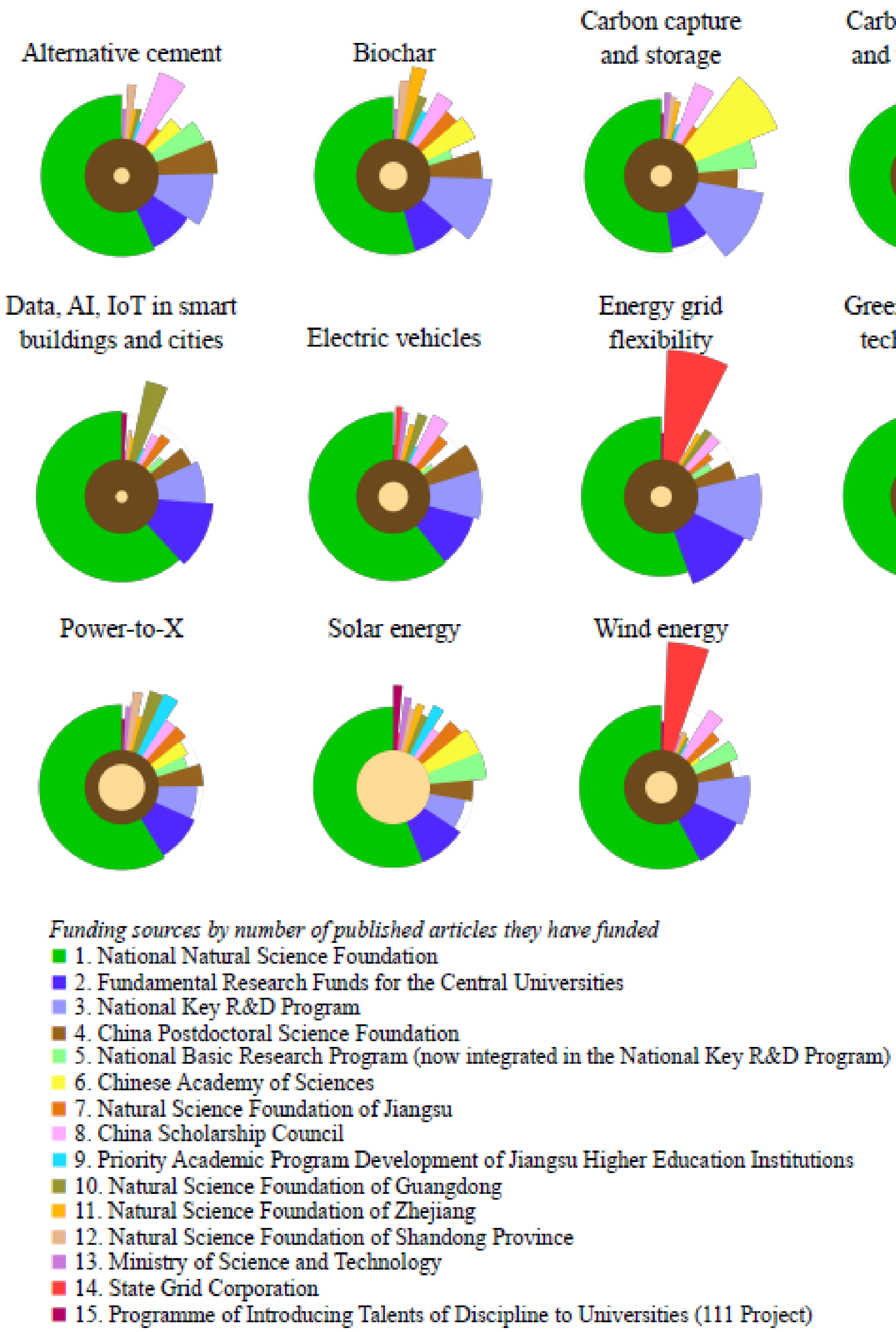
National research programs are often replicated on provincial and local levels. The four provinces of Jiangsu, Guangdong, Zhejiang and Shandong (the four Chinese provinces with the highest GDP[xii]) have provincial-level foundations among the top 15 funding sources.

In the provincial and National Key R&D Program, funding is allocated through a system involving a range of stakeholders. For science plans considered to be of key importance, e.g. AI, funding decisions are guided by a steering group with representatives from the government, party and military. Compared to such centrally managed funding decisions, the Fundamental Research Funds for the Central Universities allows for more institutional autonomy.

The Chinese Academy of Sciences, a national natural science academy that also holds the status as a think tank and provider of funding schemes, is notable among the reviewed articles, indicating it as a source of funding in the field of *carbon capture and storage*.

The State Grid Corporation – a so-called State-Owned Enterprise (SOE) – is the only company that appeared among the top 15 funding sources. It is important in the areas of *wind energy* and *energy grid flexibility*, however it is not among the top three in any of these areas.

Figure 5: Distribution of funding from the top 15 sources of funding. Slice width reflects the share of the total funding within the area allocated by a certain source of funding. Slice length indicates over- or underrepresentation compared to its share in the other areas. The size of the bright-coloured middle circle indicates the volume of articles in an area in comparison to the largest area. *Source: Web of Science, Jan 2017–Apr 2020*



6. Key research-performing actors

As seen in Table 1, there is great institutional variety across the 11 research areas. The Chinese Academy of Sciences (CAS) is among the top 3 institutions in nine out of the 11 areas. Tsinghua University is the top performer in *electric vehicles* and *wind energy*. The university also performs well in *energy grid flexibility*, where North China Electric Power University ranks highest by this measure.

Table 1: Top 3 research institutions in each focus area ranked by h-index. Each institution's h-value indicates that the given institution has published h papers that have each been cited at least h times. *Source: Web of Science, Jan 2017–Apr 2020*

Focus area	Rank	Research institution	h-index
Alternative cement	1	Hong Kong Polytechnic University	15
	2	Tsinghua University	14
	3	Chinese Academy of Sciences	14
Biochar	1	Hunan University	31
	2	Chinese Academy of Sciences	29
	3	Hong Kong Polytechnic University	26
Carbon capture and storage	1	Chinese Academy of Sciences	24
	2	Peking University	15
	3	University of the Chinese Academy of Sciences	15
Carbon capture and utilisation	1	Chinese Academy of Sciences	17
	2	University of the Chinese Academy of Sciences	14
	3	Nankai University	9
Data, AI, IoT in the context of smart buildings and cities	1	Central South University	10
	2	Hong Kong Polytechnic University	9
	3	Dalian University of Technology	8
Electric vehicles	1	Tsinghua University	31
	2	Beijing Institute of Technology	29
	3	Chinese Academy of Sciences	22
Energy grid flexibility	1	North China Electric Power University	19
	2	Tsinghua University	17
	3	Huazhong University of Science and Technology	14
Green maritime technologies	1	Chinese Academy of Sciences	12
	2	Shanghai Jiao Tong University	10
	3	Dalian Maritime University	10
Power-to-X	1	Chinese Academy of Sciences	48
	2	University of Science and Technology of China	32
	3	Tsinghua University	32
Solar energy	1	Chinese Academy of Sciences	90
	2	University of the Chinese Academy of Sciences	59
	3	Xi An Jiao Tong University	48
Wind energy	1	Tsinghua University	25
	2	Chinese Academy of Sciences	22
	3	Huazhong University of Science and Technology	21

7. Market pull initiatives

The Chinese government supports the 11 research areas in ways other than providing funding. These include steering industry development through directives and regulations, setting target levels (e.g. for production or emissions), pilot schemes and stimulating demand for an industry's products. Market pull incentives include subsidies and tax exemptions, as well as government bodies and SOEs directly creating market demand through their own purchases. Such initiatives are often applied in industries considered to be of strategic importance, such as AI, big data, IoT, electric vehicles, renewable energy, smart cities and smart energy grids. All of these are areas that are specifically mentioned in the 13th Five-Year-Plan on Technology and Innovation and/or in the Made in China 2025 strategy.[xiii] Below follows a list of market pull initiatives:

- **Tax exemptions and subsidies.** These have been used to stimulate demand and have been extensively utilised in the field of *electric vehicles* (in Chinese policies, usually in the category of *new energy vehicles*, which also includes fuel cell vehicles). These include purchase tax exemptions for consumers, introduced partly to offset the initially prohibitively expensive cost of electric vehicle (EV) batteries. Many subsidy schemes are aimed at stimulating the supply side rather than creating demand. Such subsidies have, for example, been a means of pushing the development of *wind* and *solar energy*. An estimated 1 trillion RMB has been subsidised in these two areas over the past 20 years.[xiv] Tax breaks are additionally used for aims apart from market pull, including allowing green technology companies to invest more in R&I.

- **Preferential treatment for green technology products**. As an example, several municipalities have introduced preferential license plate allocation for EVs, as a complement to the above-mentioned tax breaks, to incentivise consumers to choose EVs over fossil fuel vehicles. In Shanghai, EV owners have been granted free license plates, while owners of conventional cars need to acquire license plates through an expensive auction system.[xv]

- **Public purchases**. Examples include policies for electrifying entire bus and taxi fleets in large cities. Moreover, public security bureaus purchase AI-powered facial recognition systems, which is also related to smart city initiatives where local authorities purchase IoT equipment. Alibaba's City Brain system in Hangzhou, for example, integrates connected traffic lights and traffic cameras.

- **Directives and regulations by the central government**. In 2016 the State Council requested that 50% of all publicly purchased vehicles must be electric. Such directives from the central government are often adopted on provincial and municipal levels. Shanghai has followed the central government by requiring that 80 percent of all publicly purchased vehicles must be electric. Furthermore, a national cap on coal consumption has increased the demand for energy from renewable sources.

- **Local and provincial governments.** These play important roles implementing centrally determined initiatives. Local implementation often leaves room for influence from local political interests, which is why implementation often differs considerably between different local governments. Notably, local governments tend to tweak policy implementation to favour prominent local industry players, while remaining within a centrally defined policy framework.

8. Conclusion

China has consistently been the world's largest emitter of CO_2 since 2006. Fortunately, the country also has green ambitions, which have are reflected in China's signing of the Paris Climate Agreement, the 13^{th} Five-Year-Plan (2015–2020) and specific science, technology and industry policies. Whether China's green ambitions will endure the global economic hardship caused by COVID-19 remains an open question.

The report at hand offers more definite conclusions regarding China's performance within the 11 research areas, which have been chosen because of their potential importance for the green transition of Danish society. China is an important player within all of these areas.

China leads the global development in biochar, power-to-X and solar energy – areas in which Chinese researchers have contributed to more than 50% of the 1,000 most-cited articles globally. In other areas, China merely plays a major role. In the poorest performing area, green maritime technologies, Chinese researchers still contribute to 22% of the top 1,000 articles and thus represent a significant part of global knowledge production.

Hence, Danish research can benefit from having connections to leading Chinese research communities within all 11 areas. It is particularly worthwhile to explore the potentials for collaborations on *biochar* – an area under rapid development in China as well as emphasised by the Danish Council on Climate Change as holding substantial potential for carbon reductions in Denmark.

This report likewise offers guidance on potential Chinese partner organisations. The National Natural Science Foundation of China is by far the most important institution regarding the funding of green research. Area specific expertise is found at many Chinese academic institutions, however the Chinese Academy of Sciences, the Chinese partner of Sino-Danish Centre for Education and Research, and Tsinghua University are very well represented across all 11 areas.

It is furthermore important to underline the central role of the Chinese state in creating a market for green technologies and industries. The Chinese political system offers a range of tools for market stimulation, whose efficiency and transferability to a Danish context remain outside the scope of this report.

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[ix] https://innovationsfonden.dk/sites/default/files/2019-11/climate-panel_final-report-komprimeret.pdf & https://klimaraadet.dk/en/rapporter/known-paths-and-new-tracks-70-cent-reduction

[x] https://www.gsma.com/newsroom/wp-content/uploads/16531-China-IoT-Report-LR.pdf

[xi] The *National Basic Research Program*, also known as *Program 973* has been merged with a number of other national programs to the funding pillar: 'National Key R&D Program'. With the objective to support R&D in areas that impact people's livelihood, including the environment, it is intended to integrate basic research with application and commercialisation of technology.

[xii] http://data.stats.gov.cn/easyquery.htm?cn=E0102

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