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KNOWLEDGE IN ACTION

Faculty of Business Economics

Master of Management

Master's thesis

Systems of Innovation and Triple Helix: a historical analysis of China's innovation ecosystems

Fernando dos Santos
María Fernanda Ríos Marchant

Thesis presented in fulfillment of the requirements for the degree of Master of Management, specialization Strategy and Innovation Management

SUPERVISOR :
Prof. dr. Bart LETEN

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Covid-19 Disclaimer

This master thesis was written during the COVID-19 crisis in 2020-2021. This global health crisis might have had an impact on the (writing) process, the research activities and the research results that are at the basis of this thesis.

Preface

This thesis is written as the ending of our *Master of Management (Strategy and Innovation Management)* studies at the Hasselt University. We have fully collaborated through the whole writing process and the research activities; thus, we are jointly responsible for all the results presented. The topic covers *Innovation Ecosystems* and the evolution of China on this matter in the last 20 years. It was a fascinating and inspiring work, which opened our minds to the relevance of innovation and the challenges of managing it from a macro perspective. It was also enlightening to understand how China, once seen as a *copycat*, has rapidly become a reference in innovation in several fields. Finally, our research reinforced our belief of how important innovation is for a nation's socioeconomic development; thus, a brighter future relies on how well the several stakeholders, institutions, and policies are orchestrated to foster knowledge sharing and innovation.

General Acknowledgements

To begin with, we thank God and the universe for the graces and blessings bestowed upon us, whether in the wake of another day or through a simple motivation word from family or friends. So, we thank everyone who supported our efforts, especially in challenging times like the pandemic. Finally, we want to thank our supervisor, Prof. Dr. Bart Leten, which guided, challenged, and inspired us through this journey in search of knowledge, excellence, and growth; thus, making a true difference in what we have achieved.

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María Fernanda's Acknowledgements

So much to be thankful for! This document is dedicated to all those who in one way or another supported me in this process and always believed in me. Special mention to my beloved parents Emilio and Eva and my brother Emilio for being the roots of my existence, for their infinite love and greatest inspiration in my projects. Also, to the Manuel Montt Foundation for trusting me and supporting me unconditionally. Fernando, thank you for being an excellent partner and an extraordinary human being, working together has been a very enriching experience. Finally, I would like to thank Koen Vanthienen for his love that gives me strength and brightens my life.

Summary

The first inspiration that gave rise to this research was to try to understand what makes a country reach a level of economic development over another. Trying to find out if it was something you could handle or just a product of chance, which actors were involved, and how to do it to make it successful. Porter (1990) indicates that a nation's competitiveness depends on the capacity of its industry to innovate and upgrade. However, for this to happen it is necessary to build an environment suitable for innovation, set the rules of the game, and the direction to address innovation. Furman et al. (2002) contributes stating that the competitive advantage of a nation underlies in their innovative capacity. The three main actors who plays the major roles in knowledge generation, transfer and diffusion are government, industry, and academia.

China is a phenomenon in the global innovation landscape by its impressive economic and innovation development in the last 20 years. For instance, the country climbed from the 26th place in 2016 up to the 14th in 2019, and it is the only middle-income economy among the top 30 (Deloitte, 2019). Also it is precise to mention the extraordinary progress made by China regarding innovation indicators such as patent creation, high–tech industry development, and industrial design. That is why we agreed on to conduct our research focusing on the specific case of China.

We explore China's innovation ecosystem in our applied research carrying out longitudinal study covering the last 20 years in the history of innovative capacity of the Asian country, comparing key indicators, and finding relations between them. Our contribution relies on the deep understanding achieved regarding China's impressive evolution in innovation matters. In the literature there is no evidence of a study of such magnitude in terms of coverage, and that analyses the evolution of China (or any other country) using the frameworks of innovation systems at different levels of analysis. It brings light to how academia, industry, and government have evolved their roles and dynamics toward innovation and serves as a model to inspire other countries to follow the same path. The methodology that we use consists of applying the triple helix model at national, regional, and sectoral levels, exploring the evolution of each system as from the year 2000. In the regional analysis, the study focuses on Jiangsu, while at the sectoral level we focus on the evolution of the renewable energy sector.

The theories present in our study are: competitive advantage of nations, national innovative capacity, open innovation, radical innovation, creative destruction, innovation systems, national innovation system, regional innovation system, technological innovation system, sectoral innovation system, triple helix, quadruple helix, and quintuple helix. However, to analyse Chinese economical and innovative evolution in the period of 2000 to 2020, we focus on the following ones:

Innovation Systems (IS): According to the literature innovation systems are composed of actors (individuals and organizations) that directly and indirectly allocate resources (time, energy, capital, etc.) to produce scientific and technical knowledge. These systems aim to facilitate knowledge sharing, enable knowledge transfer, and enhance knowledge diffusion.

National Innovation System (NIS): This theory implies a macro analysis of a country's innovative capacity, encompassing the nation-specific resources, the country's innovative environment, and the strength of the linkage among the actors in the innovation ecosystem. Additionally, the level of openness toward internationalization also plays a relevant role in leveraging a nation's capacity for innovation. There are three main actors that comprises the National

Innovation Systems, the government (focused on regulation, standard setting, and funding of basic research), the industry (focused on generating commercial innovation, R&D, and product development), and the academia (focused on conducting basic research and generating scientific workforce).

Regional Innovation System (RIS): Cooke et al. (1997) argue that regions within several countries have evolved differently in terms of political, cultural, and economical forces, to the point of differentiating themselves between their own states/nations and other regions. Therefore, culminating in different models of governance powers that alter some capacities to develop innovation policies and organizations. A RIS usually implies a stronger level of involvement and autonomy of the local government to foster a region's innovative capacity, and having the stakeholders (industry, academia, government, and intermediaries) within spatial proximity is crucial to facilitate collaboration through direct interactions, continuous knowledge transfer (especially the so-called *tacit knowledge*), and technology development.

Sectoral Innovation System (SIS): Relies on the aggregation levels of products and technologies, thus it combines distinct and/or complementary technologies, and knowledge specific to a particular sector/industry (Malerba, 2002). The boundaries of a SIS can vary from a regional, national, or international level, depending on the configuration of its institutional framework and policies, thus it may be considered as a complementary approach to other frameworks instead of being a substitute one.

Triple Helix: According to the literature, the generation, transfer, and diffusion of knowledge is product of the interaction between components (academia, government, and industry), where each one acts as a helix (similar to a DNA chain). This relationship is not linear, but recursive, where eventually each component assumes the role of the other in a process called hybridization. The Triple Helix model introduced by Etzkowitz and Leydesdorff (2000), examines the interactions of institutional spheres: government-industry-academia and establishes that in knowledge-based societies the universities play a central role in the innovation process.

Implications

The implications generated in this research are expressed in three areas, related to methodology, theory, and practical implications as follows:

1) Methodology: The triple helix framework can be considered as a transversal model since its use is not limited to a specific geographic space or sector. When applying this model to national, regional, and sectoral innovation systems it allows comparison from different levels. This, in consequence, reflects the dynamics and roles that each actor adopts in each of the levels of analysis. On the other hand, all the approaches come together through the lens of network interaction and dynamic boundaries within nations, regions, and sectors. Therefore, this methodology provides a complete overview and deep understanding of the innovation process, it is highly useful to analyse complex phenomenon.

2) Theory: According to the Triple Helix theory, the university stands out as the main actor, exercising an entrepreneurial role in the process of innovation and knowledge development. However, in the reality of China, the academy occupies an important role, but it is not the one who leads. The collectivist approach of Chinese society expressed in his communist political system addresses the way of interaction between their citizens, their vision and respect to authorities exerts a great influence on the execution of the guidelines established by the government. We contribute to the theory, emphasizing the importance that exerts the specific cultural and political characteristics of a country in their innovative capacity.

3) Practical: This research can be a reference for other undeveloped, but smaller economies to illustrate what must be done to achieve sustainable development of innovation. It provides clear examples of good practice in terms of specific policies and programs to promote a suitable environment for knowledge sharing and technology development. In this sense, we develop useful insights for policymakers and people in high positions in international companies who wants to understand China's current situation and to assess the key measures to properly foster the high-tech industry development. On the other hand, our study does not give solutions to combat the imbalances present in Chinese society, nevertheless, it provides knowledge and initiatives that can be adjusted to the specific needs of each country. Furthermore, it constitutes convincing proof for the scientific and global community of the importance of investing a significant amount of the national budget in research and development to enhance innovation and economic development.

Findings

Overall, China's position as a leader in innovation and economic growth is the result of a systematic effort led by the government since 1980. Since then, China has opened to international markets and set out to modernize its economy. Plans and government programs are the heart of development and represent the foundations and guidelines for present and future position that China wants to achieve. At the national level, government action predominates over industry and academia. This is because it provides not only a coordination role, but also the conditions that facilitate innovation in terms of resources, whether human or financial. Proof of this is the policy implemented by the government to develop and attract talent, the government's efforts on improving the intellectual property rights protection, and the state funds to foster innovation.

At the sectoral level, the industry exercises leadership over other actors, since firms are the basic and essential unit in the development of new technologies, products, and services. The industries of the sector driven by the monetary incentive of the market and the support of the government are attracted to participate in the Chinese renewable energies market. The government acts as an integrator of stakeholders to overcome industry obstacles such as high cost of technology and product development, and small markets weakness in the manufacturing industry. In the case of academia, its role is crucial for the dynamics that are generated within the network: universities and scientific institutions act as bridges between the multiple nodes promoting the transfer of knowledge throughout the sectoral network.

At the regional level, industry is considered the main actor in terms of execution, production, and scaling up innovation (thus increasing the region's competitiveness and economic development). Although the central government establishes the programs, the local government has some authority and autonomy to determine investment in science and technology. In this sense, the government has an important leadership role in terms of innovation sponsorship and guidance (rules and priorities establishment), while the academia adopts a more coordinative and networking role supporting stakeholders through joint efforts for innovation and entrepreneurship.

Limitations and Future Research

There are some limitations present in our study, we specify them as follows: First, the qualitative information and events presented may be subject to bias since the main source of those were institutions interested in promoting their successful initiatives to build a positive reputation (such as the Chinese government itself for example). Second, it is not possible to generalize the research findings (including quantitative ones), since the samples were based on limited success cases without amplitude/variety for broader statistical measurement of correlation or causation. Furthermore, there is no consensus on the literature about the exact extent of KPIs that must be applied to measure innovative performance in different contexts, or to determine which factors may have greater/lesser impact. Third, due to time constrains versus the magnitude of the research coverage (encompassing national, sectorial, and regional dimensions of complex innovation ecosystems in a broad timeframe of 20 years), combined with the authors' lack of knowledge of the Mandarin language, it may be possible that some relevant events and/or data was not contemplated.

This study can be enlarged by considering also other countries, we consider that additional efforts might be conducted to discover which factors present greater impact on innovative performance at different realities and country profiles. Specifically, future research is suggested to analyse the influence of country-specific factors on the development of innovation, such as idiosyncrasies and culture, political and economic stability, and political regime.

Keywords: Innovation, Innovation Systems, Innovation Ecosystem, National Innovation System, Regional Innovation System, Sectoral Innovation System, Triple Helix, China, Jiangsu, Policies, Government, Industry, Academia, Science and Technology, Economic Development.

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1. Introduction

What is it that allows a nation to develop and achieve a higher standard and performance than others? Is there a common factor that determines sustained success or is it just a matter of chance? The answer is yes, there really is a common denominator that enhances the development of countries and, as in the concepts used in management, constitutes the competitive advantage of nations. Following the logic of this concept, it is also necessary to indicate that this differentiating factor can be managed. But how is it possible to handle it? What actors participate in this environment? How are they related and what are the optimal dynamics that allow for superior performance? How can the success or failure of countries be measured in terms of this competitive advantage?

According to Porter (1990), a nation's competitiveness depends on the capacity of its industry to innovate and upgrade. However, to this occur is precise to build an environment that be suitable for innovation, set the rules of the game and the direction to address innovation, thus government is the actor who plays this role. In addition, academia establishes mechanisms to support basic research and higher education, and the accumulated stock of knowledge on which new ideas are developed and commercialized. Therefore, the three main actors that interrelate to generate an environment where innovation thrives are Industry, represented by companies as a basic unit, Government, and Academia.

In line with Porter's ideas, the characteristics that a national environment must have to be conducive to the development of competitive advantage are three. First, it must permit and support the most rapid accumulation of specialized assets and skills, second it must afford better ongoing information and insight into product and process needs and finally, when the national environment pressures companies to innovate and invest, they both gain a competitive advantage and upgrade those advantages over time. A more recent study by Furman et al. (2002), called "The determinants of national innovative capacity" illustrates in more detail that the competitive advantage of nations underlies the National innovative capacity. This capacity depends on the presence of a strong common innovation infrastructure: cross-cutting factors contributing to innovativeness throughout the economy.

There is sufficient evidence in the literature to support the idea that innovation plays a central role in the long-term economic growth process. However, in this process, over time, companies have realized that they do not have all the financial resources, knowledge, or qualified personnel to generate new technologies and/or develop new business models. In response to this problem, innovation has evolved towards a new paradigm where firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to develop their technology. In this evolutionary change a new concept arises, that of open innovation, defined as: "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" (Chesbrough, 2006, p. 1).

The organized systems for the development of innovation or Innovation Systems have different characteristics and can be defined in several ways. This paper explains each of the existing classifications and their characteristics. In addition, it will be emphasized the dynamics associated with the different innovation systems and their interrelation with the actors that are part of it.

Several types of frameworks that shape the development of innovation in a country are present in the literature, each from a specific perspective. A national innovation system is limited to the action of the three main actors in a specific country, while the regional system does the same, but within a regional context. Other systems such as technological and sectorial are even more specific since they study the development of a certain technology or technological sector. On the other hand, there is the triple helix model and its derivatives (quadruple and quintuple helix) that highlight the dynamics and roles that each of the actors assumes in the development of the innovation system. Existing approaches serve as guides for analyzing innovation, nevertheless, each one separately provides a limited vision. In order to analyze complex phenomena in depth, it is necessary not only to adopt different points of view, but also to cover a determined period of time.

In the global innovation landscape, China is a phenomenon by its impressive economic and innovation development in the last decades. It has climbed from the 26th place in 2016 up to the 14th in 2019, and it is the only middle-income economy among the top 30 (Deloitte, 2019). Moreover, there has been significant progress made by China in its innovation indicators from various aspects, ranking top in terms of domestic patents, industrial design, original trademark, thigh-tech net exports and export of creative products, etc. The truth is that China today is entering into a new stage of development for innovation. This study aims to understand how China has presented such impressive evolution in innovation matters in recent years. It may bring light to how academia, industry, and government have evolved their roles and dynamics toward innovation. For this reason, we will explore China's innovation ecosystem in our applied research carrying out longitudinal study covering the last 20 years in the history of innovative capacity of the Asian country, comparing key indicators and finding relations between them.

The methodology used consists of applying the triple helix model at different levels, national, regional, and sectoral, exploring the evolution of each system over 20 years. In the regional analysis, the study focuses on Jiangsu, while at the sectoral level the evolution of renewable energies is studied. The largest source of data corresponds to official documents issued by Chinese government agencies or reports belonging to international organizations. The study aims to answer five research questions who addresses the innovation development of the Asian giant. The first one focuses on how China's national, regional, and local governments are organized to foster innovation and technological/scientific development, indicating their main institutions and policies. The second one explores the evolution of China's academic landscape and performance, and the programs that are in place to foster R&D collaboration within the industry. The third one examines how China's industry has evolved in terms of R&D investment, new products development, and international trade. The fourth one analyses the main differences within the national, regional, and sectorial dimensions of China's innovation ecosystems. Finally, the fifth one indicates the main results that China has achieved in terms of patents/inventions and attraction of foreign trade investment.

The main conclusion of this study shows that, overall, China's position as a leader in innovation and economic growth is the result of a systematic effort led by the government since 1980. Since then, China has opened to international markets and set out to modernize its economy. Plans and government's programs are the heart of development and represent the foundations and guidelines for present and future position that China wants to achieve.

At the national level, government action predominates over industry and academia. This is because it provides not only a coordination role, but also the conditions that facilitate innovation in terms of resources, whether human or financial.

At the sectoral level, the industry exercises leadership over other actors, since firms are the basic and essential unit in the development of new technologies, products, and services. The industries of the sector driven by the monetary incentive of the market and the support of the government are attracted and stimulated to participate in the Chinese renewable energies market.

At the regional level, industry is considered the main actor in terms of execution, production, and scaling up innovation (thus increasing the region's competitiveness and economic development). Although the central government establishes the programs, the local government has some authority and autonomy to determine investment in science and technology. In this sense, the government has an important leadership role in terms of innovation sponsorship and guidance (thus establishing priorities and rules, and providing financial support), while the academia adopts a more coordinative and networking role (thus supporting stakeholders through joint efforts for innovation and entrepreneurship).

2. Literature Review

2.1. Innovation Systems

As previously mentioned, innovation does not happen by itself, nor does it happen in a simple, predictable, and linear environment. That is why scholars and governments started to dedicate themselves to identifying the *pieces of this puzzle* that makes innovation possible and potentially can leverage it, and not only the *pieces* themselves, but also the dynamics and interdependence between them, thus landing on the concept of innovation systems.

For a better understanding, this research uses the definition that "systems are made up of components, relationships, and attributes working toward a common objective" (Carlsson et al., 2002, p. 2). In this perspective the components of a system are the actors, attributes, and resources that compose it; whereas actors refer to organizations, individuals, firms, institutions, governments, among others; while the attributes and the resources (physical or intangible ones) refer to technology, techniques, legislation, and traditions. Therefore, a system's result is determined by the sum of its parts, which act interdependently and influence each other through dynamic relationships.

Moving to the concept of innovation systems, the literature commonly states that these systems are composed of actors (individuals and organizations) that directly and indirectly allocate resources (time, energy, capital, etc.) to produce scientific and technical knowledge. Thus, one of the missions of an innovation system is to facilitate knowledge sharing, and this is important because even though we live in an increasingly connected world where individuals may have access to the same stream of information, those individuals do not necessarily apply it into comparable knowledge (Katz, 2006). Furthermore, Carlsson et al. (2002) corroborate this statement when defining that one of the fundamental relationships in innovation systems involves transfer or acquisition of knowledge and technology, thus enabling nations to improve their innovative capacity.

Lundvall et al. (2002) argue that the idea of innovation systems became widely discussed and diffused as from the middle of the 1980s with the concept of National Innovation Systems (NIS) and, from this point on, several regional/national authorities and institutions (such as OECD[1], the European Commission and UNIDO[2]) have adopted the concept as part of their science and technology policy analysis, underlying innovation, industrial transformation, and economic growth. Furthermore, the authors state that the innovation system framework became more relevant due to the needs of policymakers and students of innovation to understand the contrasts within the research systems of different countries, thus combining innovation studies with general economics to investigate the differences regarding the nations' growth rate. Other scholars confirm this approach stating that "Successful economic development is intimately linked to a country's capacity to acquire, absorb, disseminate, and apply modern technologies, a capacity embodied in its NIS" (Metcalfe and Ramlogan, 2008, pag.4).

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[1]The Organization for Economic Co-operation and Development (OECD) is an international organization that works to build policies that foster prosperity, equality, opportunity and well-being. Currently with 37 member countries globally, the OECD works together with governments, policymakers and citizens on establishing evidence-based international standards and finding solutions to a range of social, economic and environmental challenges (from improving economic performance and creating jobs to fostering strong education and fighting international tax evasion).

[2]The United Nations Industrial Development Organization (UNIDO) is the specialized agency of the United Nations that promotes industrial development for poverty reduction, inclusive globalization and environmental sustainability aiming to promote and accelerate inclusive and sustainable industrial development (ISID) in the current 170 member states globally.

It is possible to identify an increasing number of studies on innovation systems over the past few decades, culminating to the emergence of new approaches and frameworks including the National Innovation Systems (Lundvall et al., 2002), Regional Innovation Systems (Cooke et al., 1997), Technological Innovation Systems (Bergek et al., 2008) and Sectoral Innovation Systems (Malerba, 2002). In the next sections this study will explore further the main characteristics, the main differences, and some examples of the distinct approaches to innovation systems.

2.1.1. National Innovation Systems (NIS)

We begin this section with a noteworthy statement from Lundvall et al. (2002, p. 215) "As long as nation states exist as political entities with their own agendas related to innovation, it is useful to work with national systems as analytical objects". Corroborating with this statement, Balzat and Pyka (2005) argue that one possible reason that the NIS approach may be an adequate conceptual framework for the empirical study of innovation processes on the country level rely on the fact that early applications of innovation systems have been found to be strongly nation-specific because different countries may have distinct institutional capacities for innovation.

Therefore, in their research the authors propose a NIS framework where *actors* (institutions and their interdependencies) execute *innovative efforts* (such as investment in R&D-related activities on the macroeconomic level) integrated within an ecosystem supported by the nation's *knowledge base* (such as the level of inventiveness, patent data, scientists, education system and workforce) and by the nation's *financial conditions* (such as the national financial markets, the level of capital costs in a country and the availability of venture capital to firms).

Additionally, the level of openness/internationalization also plays a relevant role in leveraging a nation's capacity for innovation. For instance, the literature has shown that in the last decades several nations have created policies to facilitate the inflow of foreign investments, scientific knowledge, and talented workforce. Thus, when properly supported by policies and innovation programs, the inflow of foreign resources increases a nation's ability to absorb, learn and develop new technologies. On the hand, the outflow of a nation's technology, such as exports or R&D initiatives overseas, can also potentially foster the absorption of external knowledge and facilitate the collaboration within multinational firms, universities, and research institutes.

In terms of actors, the early literature identifies 3 main actors that comprises the National Innovation Systems, namely the *government* (focused on regulation, standard setting and funding of basic research), the *industry* (focused on generating commercial innovation, R&D and product development) and the *academia* (focused on conducting basic research and generating scientific workforce).

In general, the NIS framework focuses on the role of the *industry* as the main actor which develops, produces, and commercializes innovation, while the *government* and academia may play a supporting role (Watkins et al., 2014). Ultimately, understanding the connections within the actors involved in innovation is key to improving technology performance. For instance, a publication of the OECD (1997, p.9) suggests that "the innovative performance of a country depends to a large extent on how these actors relate to each other as elements of a collective system of knowledge creation and use as well as the technologies they use".

To support our understanding of distinct innovative profiles from different nations, the Exhibit 1 shows the performance of the G7[3] countries' national innovation systems compared to all OECD countries in 2010. This set of data indicates the competences and capacity of the science base and the business sector to innovate, and the conditions for entrepreneurship. For instance, through these KPIs it is possible to identify that at the time Germany was stronger in terms of public R&D expenditures while the United Kingdom had a higher concentration of the top 500 universities and number of publications in the top-quartile journals. On the other hand, Japan stood out in terms of business R&D expenditure and concentration of top 500 corporate R&D investors, while the United States presented the strongest venture capital, showing some emphasis in the private sector in comparison to the other countries in the group. Finally, it is important to clarify that it is not the intention of this research to deeply explore these KPIs in the literature review (since some KPIs will be further explored during the empirics), but the main goal in this section is to exemplify how nations may differentiate in terms of their innovative efforts at the country level.

Exhibit 1 – OECD Comparative Performance of National Science and Innovation 2010

Country	Science base			
	Public R&D expenditures (per GDP)		Top 500 universities (per GDP)	Publications in the top-quartile journals (per GDP)
Canada	(e)	123,80	120,48	135,91
France	(e)	129,28	86,58	87,06
Germany	(ad)	147,58	106,69	88,38
Italy	(e)	67,99	101,75	81,38
Japan		98,33	48,69	44,54
United Kingdom	(e)	86,25	121,03	148,37
United States	(bc)	102,18	95,64	85,22

Country	Business R&D and innovation			
	Business R&D expenditure (per GDP)		Top 500 corporate R&D investors (per GDP)	Trademarks (per GDP)
Canada	(e)	78,48	46,94	126,55
France	(e)	110,93	124,56	102,08
Germany	(e)	133,55	120,20	105,78
Italy	(e)	51,79	86,47	88,26
Japan		157,49	147,54	52,69
United Kingdom	(e)	95,62	116,85	105,32
United States	(c)	138,46	115,82	101,42

Country	Entrepreneurship					
	Public R&D expenditures (per GDP)		Venture capital (per GDP)		Patenting firms less than 5 years old (per GDP)	Ease of entrepreneurship index
Canada	(e)	123,80		98,37	73,07	132,99
France	(e)	129,28	(d)	113,47	83,46	103,24
Germany	(ad)	147,58	(d)	96,10	103,20	98,69
Italy	(e)	67,99	(d)	12,47	71,01	145,85
Japan		98,33		..	20,13	94,14
United Kingdom	(e)	86,25	(d)	112,32	111,11	200,00
United States	(bc)	102,18	(d)	139,24	109,22	113,28

Source: *data extracted on 11 Feb 2021 14:00 UTC (GMT) from OECD.Stat.*

a: National estimate or projection.
b: Federal or central government only.
c: Excludes most or all capital expenditure.
d: Overestimated or based on overestimated data.
e: Provisional.

Note: *Indicators are normalized (by GDP or population) to take account of the size of the country. The country's values are compared to the median value observed in the OECD area, i.e., the middle position among OECD countries for which data are available. The use of the median avoids a statistical bias towards large players that skew the average while still reflecting international rankings. All indicators are presented in indices and reported on a common scale from 0 to 200 (0 being the lowest OECD value, 100 the median value, and 200 the highest) to make them comparable.*

[3]The G7 brings together the leaders of the world's leading industrial nations. The annual G7 summits have over the years developed into a platform for determining the course of multilateral discourse and shaping political responses to global challenges. It complements the role of the G20, which is widely regarded as the framework for ongoing global economic coordination. The G7 summit gathers leaders from the European Union and the following countries: Canada, France, Germany, Italy, Japan, the United Kingdom, the United States.

2.1.2. Regional Innovation Systems (RIS)

The approaches to the NIS have proven to be instrumental to tackle issues such as innovation policy, national economic development, and firms' competitiveness. However, how to deal with the fact that the socioeconomic and political dimensions within a country (and between countries) are not homogeneous? So, this section aims to explore this perspective.

To begin with, Cooke et al. (1997) argue that regions within several countries have evolved differently in terms of political, cultural, and economical forces, to the point of differentiating themselves between their own states/nations and other regions. Therefore, culminating in different models of governance powers that alter some capacities to develop innovation policies and organizations. The authors also highlight the importance of distinguishing between different types of regions, such as *cultural regions* (for example, the Basque Country or Scotland) or *administrative regions* (for example, Flanders and Wallonia in Belgium).

Additionally, Asheim and Coenen (2005) argue that regional governance may be represented by private and/or public organizations, such as industry associations, chambers of commerce, regional agencies, among others; with certain level of power delegated from the national level or supra-national level (such as the European Union) to promote enterprise and innovation support.

In terms of regional capacity to mobilize innovation resources and capabilities, Cooke et al. (1997) mention that there are three key dimensions that may differentiate regional innovation: 1) *financing*, referring to the regional budgetary capacity and level of autonomy in controlling, executing and managing their spending; 2) *infrastructure*, referring to the physical arrangement of capabilities within a regional space in order to enable multiple relations between the different actors, such as the density and quality of telecommunications networks, technologies, airports, rail networks, regional scientific and technological parks, and; 3) *general competences*, referring to the region's support to innovative activities through its own educational and training system (such as universities related to the areas relevant for the region) and the proactive support from the regional government covering activities such as regional procurement, regional policies for industrial and technological development, and regional science and technology programs.

Finally, the authors state that the combination of the *financing*, the *infrastructures* and the *general competences*, would enable an innovative regional cluster to provide access to networks for collaborative operation (connecting other firms, customers, suppliers, or partners in their sector), to take advantage of knowledge-centers (such as research institutes and contract research organizations, universities, and technology-transfer agencies), and to receive support from government departments, chambers of commerce, training and promotion agencies, governance structure of private associations and public economic development.

According to Asheim and Coenen (2005), some scholars underestimate the importance of Regional Innovation Systems (RIS) arguing that in a globalizing economy the actors within a RIS often depend on structures and developments realized outside the region. However, the authors defend the relevance of regional systems arguing that a region's innovative contribution should not take into account *the whole innovation value chain* but the concentration of *core innovative activities in the region* as well the region's autonomous government structure. Moreover, Acs et al. (2001) corroborate to the relevance of the regional approach to the innovation systems by arguing that several studies suggest that innovation activities are not equally distributed in space.

For instance, production of new scientific and technological knowledge has a likelihood to cluster geographically because distance plays a key role in knowledge sharing within the actors of an innovation system. For example, firms specialized in a particular technology or knowledge may benefit from cooperation with partners with spatial proximity within regional clusters because both depend on tacit knowledge, direct interaction, and trustful relationships. To illustrate it, this research explores two examples of RIS with distinct configuration and scale, namely the Emilia-Romagna region in Italy, and Berlin in Germany.

Emilia-Romagna Regional Innovation System in Italy: It promotes research-industry collaboration through a Regional High-Tech Network composed of 82 Industrial research laboratories and 14 Innovation centers who invest their resources and collaborate in the exploitation of research results, new knowledge development, adoption of new technologies and innovation across sectors such as agri-food, construction, energy and environment, ICT and design, life science, mechanics, and materials (Regione Emilia-Romagna, 2021). The region also encompasses associations of public and private bodies (such as companies, research centers and training institutions) and a joint stock consortium that coordinate industrial research, facilitate relationships within business incubators and startups, and promote investments in the region in partnership with public bodies and investors. In terms of institutional framework and setup, the regional government plays a central role in designing innovation and economic development policy and strategy through strong alignment and consultation with local stakeholders. In terms of scientific research, the public R&D spending represents only 0.5% of GDP until 2013, and the regional system is characterized by a diffused presence of universities and research organizations in the main cities. Finally, some intermediary institutions (such as business organizations, chambers of commerce, public agencies, and competence centers) play a networking bridging role within the stakeholders to foster local development by promoting innovation culture, workshops and seminars, matching events, training courses, etc. (European Commission, 2016).

Berlin Regional Innovation System in Germany: With around 40,000 new companies founded each year, Berlin is considered Germany's start-up hub, with a strong entrepreneurial culture, tech conferences, start-up contests, incubators, and investors attracting founders from all over the world. Unlike the previous example in Italy, the R&D expenditure in Berlin relies heavily on government investments due to a lack of industrial actors in the region. In 2007, the share of public expenditure in R&D was around 33.2% (well above the German national public R&D expenditure of 13.9% at the same period). This means that the local government plays a role beyond a *coordination function,* but it also acts as a strong *sponsor* of the local innovation system. In terms of institutional framework and setup, Berlin has a large degree of autonomy, including legislative authority and right to raise some taxes and complete freedom to design and implement innovation and education policies. Finally, some intermediary institutions (such as the Technology Foundation Berlin, the Investment Bank Berlin, and the Berlin Partner) play important roles related to knowledge transfer, advisory and consultancy to enterprises, founding instruments to support innovation, and networking bridging connections to attract new business (European Commission, 2011).

To conclude, as presented on the previous examples from Italy and Germany, a RIS usually implies a stronger level of involvement and autonomy of the local government to foster a region's innovative capacity, and having the stakeholders (industry, academia, government and intermediaries) within spatial proximity is crucial to facilitate collaboration through direct interactions, continuous knowledge transfer, and technology development.

2.1.3. Technological Innovation Systems (TIS) and Sectoral Innovation Systems (SIS)

One of the next questions that arises with the evolution of concepts and practices of innovation systems is: Would the rather generic approach of national and regional systems be sufficient to tackle specificities of certain industries or segments? To begin with, it is important to recall that the frameworks of national and regional systems of innovation have proven to be valuable for innovation development, however, due to all the heterogeneity of the innovation systems and specificities of each market, it becomes clear that *one size fits all* does not apply for innovation; therefore, scholars started to research and develop more focused approaches and frameworks.

Technological Innovation Systems (TIS)

A Technological Innovation Systems (TIS) can be defined as a focused approach to innovation dedicated on *developed technological fields* and/or on the *arise and propagation of radical innovations*, thus covering *how the innovation system around a particular technology functions* (Bergek et al., 2015). More specifically, the TIS framework covers an analytical view of new industries and its *technology-specific factors*, policy strategies, obstacles, and complexities related to the interaction to other systems such as sectoral and national innovation systems.

Bergek et al. (2008) adopted a functional approach to analyze the differences between a TIS and its predecessors. For instance, the authors argue that, although the NIS and RIS frameworks may have a similar structure to the TIS, they do not cover *specificities related to technology*. For this reason, the authors propose a framework to tackle what is produced/achieved in the TIS rather than focusing only on the interaction of structural components. They have identified 7 functions that must be fully carried on ensuring the optimal success of a TIS, namely: knowledge development, influence on the direction of the research, entrepreneurial experimentation, market formation, legitimation, resources mobilization and development of positive externalities (i.e., facilitation for entrants and diversity of actors within the TIS). To illustrate how some of those functions are specific to TIS, this paper explores some examples mentioned by the authors in their article *Analyzing the functional dynamics of technological innovation systems: A scheme of analysis*.

In terms of *entrepreneurial experimentation*, it is important to generate incentives to help new technologies to enter the industry and reduce uncertainty related to new applications and markets. It happened for example with the wind turbines sector in Germany during the early phase of the system's evolution, where the federal R&D policy subsidized development of new designs to foster beliefs in growth potential, also supporting many industrial firms and academic organizations to test and develop diversification of turbine sizes and designs. For instance, "as a result of some of these experiments, at least 14 firms entered wind turbine production, including academic spin-offs, diversifying medium-sized mechanical engineering firms and large aerospace firms, all of which brought different knowledge and perspectives into the industry" (Bergek et al., 2008, p. 416).

In terms of *market formation and legitimation*, it is important to create policies and market conditions to support a new technology to overcome challenges such as unclear demand from potential customers, poor price or performance, lack of standards, limited market size, low social acceptance, lack of compliance with relevant institutions, etc. For instance, in another example from Germany, related to the technology of solar cells in the early 1990s, it suffered from lack of support from the federal government that didn't engage to launch a nationwide regulatory change in favor of the diffusion of this technology, so in response to it, many organizations and activists began lobbying at several cities and local events until they got enough support and enabled contracts within suppliers and interested cities, this effort brought visibility upon the public interest in increasing the rate of diffusion, thus the market formation and legitimacy of solar cells were made clear and enabled further technology development and regulatory support from the government.

Sectoral Innovation Systems (SIS)

As already explained, although innovation is commonly linked to new technologies, it can be said that this is not the only perspective, hence the importance of another complementary approach as the Sectoral Innovation Systems (SIS) framework. Naturally, the SIS framework draws from basic concepts of the evolutionary theory of Innovation Systems, thus also embracing the main actors (industry, academia, and government), the knowledge and learning processes, the mechanisms of interactions among the actors including their resources, demands, and the policies.

A key difference in a SIS approach versus the previous relies on the *aggregation levels of products and technologies*, thus it combines distinct and/or complementary technologies and knowledge specific to a particular sector/industry (Malerba, 2002), for example, a SIS can embrace a broader sectoral perspective such as *all kind of computer hardware*, or a narrower perspective such as *software for printers*.

For a better understanding of a SIS, consider for example the transportation sector of China, which encompasses a diversity of sub sectors such as airplane, high-speed rail, automobile, shipbuilding, etc. Technology policy is crucial to enable development of the sector and facilitate knowledge transfer, however, China faced several challenges to attract foreign direct investment and high technology from developed countries until the 1980s. So, to cope with such limitations the government launched policies to motivate foreign investors to provide capital, equipment, and technology to China, getting in exchange free market access to the products. Additionally, the government also designated many large state-owned firms from different regions to set up joint ventures with foreign firms (Chan and Daim, 2012).

A Sectoral Innovation System can be considered as a framework that combines the National Innovation System framework and a Technological Innovation System framework. For instance, a SIS is broader than a TIS because it encompasses several technologies that are sector-specific, on other hand, a SIS may be narrower than a NIS because it has specific policies that may not apply to all other sectors at the national level. Finally, the boundaries of a SIS can vary from a regional, national, or international level, depending on the configuration of its institutional framework and policies, thus it may be considered as a complementary approach to other frameworks instead of being a substitute one.

Finally, it worth briefly exploring a complementary theoretical concept called *Socio-technical Innovation Systems* (ST-systems). To begin with, as previously discussed, most of the approaches and frameworks of innovation systems focus on the *source of innovations* referring to the *production side* where innovations emerge. Hence, Geels (2004) proposes the ST-systems approach which explicitly *incorporates users* within the innovation system analysis and draws more attention to the *social groups interaction.*

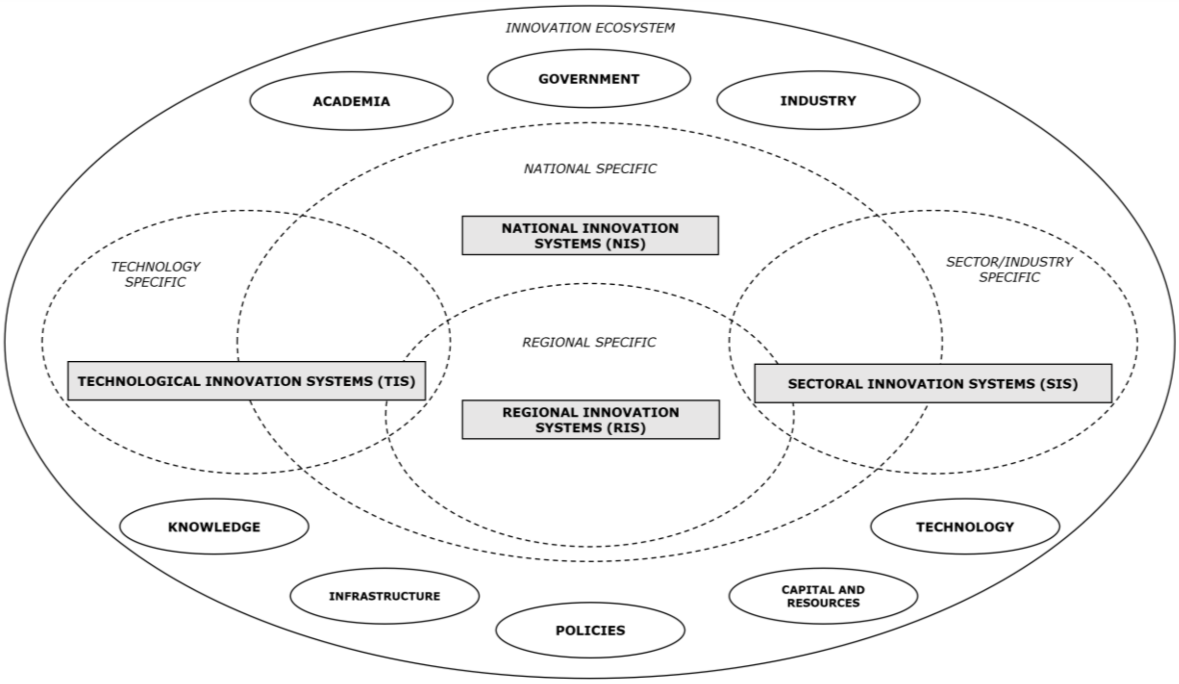
More specifically, consider for example the social media nowadays, which must cope with several challenges beyond technological performance, such as platforms like Facebook and Instagram that must handle issues related to the users' behavior. This is a compelling example on how the integration of technology and social groups can potentially shape people's interaction leading to problems such as consumption addiction or political polarization. Hence, Geels (2004) argues that a socio-technical lens allows the actors within the ST-system to frame technology not only as a tool but also as a *dynamic integration of social interactions* and, in order to cope with it, the policymakers and actors within a ST-system should coordinate the activities beyond regulatory aspects (such as government regulations, property rights, patents, tax, trade laws, etc.) but they should also foresee issues related to normative and cognitive rules such as values, beliefs, habits, preferences, culture, and expectations within the relationship of the society with new technologies.

To conclude this section dedicated to Systems of Innovation, we suggest that the approaches found on the literature are complementary to each other's. For instance, the role and participation intensity of each main actor may vary according to the region/nation/sector/technology in a specific context. However, all frameworks encompass how governments, firms, academia, and intermediaries interact and collaborate to foster innovation and knowledge sharing. In some contexts, the government has a proactive regulatory and sponsorship role, while in other contexts the government has a more passive role while the industry leads the coordination and lobbying to push the market further. Moreover, some nations have specific national policies for specific technologies/sectors, while others delegate such authority to specific regions or institutions. Finally, the literature does not mention the academia as having a leadership role, instead it emphasizes the supportive position of universities by developing basic science and skilled workforce, thus often depending on government and industry to gather investments and to handle education policies in favor to research. To summarize this understanding around to the Systems of Innovation *interconnection* and its *specificities* we suggest a conceptual visualization at Figure 1.

2.1.4. Innovation Systems Internationalization

It is possible to identify some sort of dichotomy in regard to the boundaries of different approaches of innovation systems, where some authors establish clear limits for the extent of their analysis, while others emphasize that the study of innovation systems is strongly heterogeneous, and the interrelations are increasingly complex and dynamic. Nowadays, the systems of innovation interact globally, so different systems may have distinct capabilities for innovation and competitiveness (Niosi and Bellon, 1994, as cited in Watkins et al., 2014). Hence, global linkage and interactions among systems of innovation have been growing in benefit to the openness to the external knowledge flows, such as collaboration between leading research universities from different countries and joint R&D activities within multinational companies.

Figure 1 – Conceptual Visualization of Innovation Systems



López (2020) mentions that the different models of innovation systems can work in different contexts, but all of them need a proper regulatory framework permeating several policies of a country from several perspectives such as industry, economy, tax, higher education, among others. Nonetheless, all the modifications or reforms must be integrated and consistent to the country's reality. Additionally, in a study of internationalization of innovation systems, Carlsson (2005) emphasizes that country-specific factors such as national networks and policies are still strongly relevant. Thus, there are considerable differences on the level of systems internationalization, and nations present different types of flows and intensity regarding their openness to share and/or receive scientific and technological knowledge.

A clear example of how internationalization may bring benefits to the innovative capacity can be found in China. Before opening to the external market, the Asian country had faced several challenges caused by his deficient technology, it had to acquire it from developed countries (USA and Europe) in order to improve their innovative capabilities and competitive advantage. However, in the past 40 years the Chinese government has been pushing research institutions and firms towards internationalization and has both increased China's foreign direct investments and attracted investments from developed countries. As a result of these policies China is currently an important investment destination and is the second largest foreign investor in the world (arising from the 26th place in the global ranking 2002). Chinese firms have been matching, learning, imitating, and developing new technology thanks to the accumulation of rich knowledge and experience from international exploration and collaboration (Chen and Li., 2019).

China's government has orchestrated several measures to foster innovative capacity and competitive advantage through internationalization, such as the implementation of new policies, changes on the controls related to international investments and partnerships, definition of priority sectors and countries to invest, and has allowed firms and research institutions to setup international joint ventures and cooperative production.

After the 2000's the Chinese government intensified the engagement on mergers and acquisitions (M&A), R&D alliances and Greenfield investment, which refer to the setting up of research institutions overseas. Hence, in 2016 there were more than 37,200 foreign firms in China from more than 190 countries and regions around the world, and more than 1,500 Chinese companies established R&D affiliates in 88 countries and regions globally (Chen and Li., 2019).

Finally, as an illustrative example of industry development, consider the Artificial Intelligence Technology, China is currently one of the world's most active countries in those applications. In 2018 the country accounted for 60% of the global investment and financing in Artificial Intelligence, and local governments across China have introduced tax incentives, subsidies, and talent development efforts to attract competitive firms to the country (Deloitte, 2019).

2.1.5. Innovation Systems Dynamics: Networks and Policies

Due to the complementarity and overlapping that this research has found through the different innovation systems frameworks, this section aims to briefly describe key aspects that, as per our understanding, permeate all innovation systems despite their specific focus. Hence, this study will summarize key dynamics related to networks and policies because it shapes the relationships within an innovation system and, as stated by Etzkowitz and Leydesdorff (2000), the relationship and interactions within an innovation system influence the actor's intentions, strategies, projects, structures, and resources toward innovation.

To begin with, it worth highlighting the importance of analyzing the systems networks not only in terms of structure, connections, and actors, but also in terms of *learning processes* and *relationships dynamics*. For instance, conflicts of interest between the parties involved may rise, established social and technological issues may need to be solved, political background, and societal negotiations may represent barriers (Mierlo et al., 2010). Hence, *weak networks* hinder the linkage between actors compromising their complementarities, the interactive learning, and the creation of new ideas; while *too strong networks* may suffer from focusing excessively internally and being *blind-sided* by external factors (Carlsson and Jacobsson, 1997, as cited in Woolthuis et al., 2005).

As an illustrative example of network success and failure, a longitudinal analysis of biotechnology clusters in Australia between 2003 and 2014 has shown that strong connections at the local level fostered collaboration and early-stage funding for research and science development, but the weak linkage with distant partners hindered the collaboration towards commercialization and international markets (Gilding et al., 2020).

In addition to the analysis of networks' strength for innovation, according to Rubach et al. (2017) it is important to pay attention to the policies and relationships that may differ between innovation clusters. For instance, in a case study conducted over four successive policy initiatives to stimulate regional innovation in Norway from 2004 to 2016, the authors found out that policies created to benefit individual firms had a positive effect to attract and mobilize local firms to join the clusters allocating their staff and business resources to the innovative activities, while the founders of such clusters (such as the government, universities, research institutes and sponsor firms) focused on a supportive role related to policy creation and knowledge sharing.

On the other hand, when policies changed to a broader perspective focusing on new businesses and regional development, the new firms who joined the innovation clusters did engage mainly for gathering information with low level of resources allocation, while in this case the clusters' founders had to adopt a leadership role acting as influencers and taking part in making decisions. So, this study shows that the policies shaped the level of engagement of the networks over time.

From a broader perspective, the concept of innovation policy has commonly referred to policies which support the innovative activities to generate new or improved products, services, processes, or knowledge to the society and/or market. Thus, traditional policies mainly focus on R&D support and cover issues such as tax relief or subsidies for the actors within an innovation system, subsidies for business consultancy and learning networks, and infrastructure building/improvement (Hobday et al., 2012). However, the literature has shown that a lot has been evolving in the last decades, where policies have been moving from linear approaches (focused mainly on R&D infrastructure provision, financial innovation support for companies, and technology transfer) to broader perspectives covering issues such as developing research excellence, attracting global companies and institutions to innovation systems, fostering high-tech/creative industries, and stimulating spin-offs.

In their study, Tödtling and Trippl (2005) argue that innovation strategies and policy approaches cannot have a unique framework to effectively tackle different types of problem areas and challenges for innovation in different regions, nations and/or sectors. The authors highlight that focusing only on R&D and its technological facet is not enough, thus policies must deal with the educational, commercial, organizational, and financial extents of innovation. For instance, policy formulation requires close interaction and communication within the actors in an innovation system and, to maximize the results, the strategy should be focused on strengthening the actors, regions, and sectors with the highest potential to compete and innovate.

Finally, Woolthuis et al. (2005) propose a framework for policymakers to analyze innovation systems and adjust the policies to tackle challenges related to four dimensions: *1) Infrastructure:* communication infrastructure, energy supply, broadband, telephone, testing facilities, patents, training, etc.; *2) Institutional:* technical standards, labor law, risk management rules, health and safety regulations, contracts legal system, intellectual property protection, social norms and values, culture, risk appetite/averseness, etc.; *3) Interaction:* relationships, links and interactions within actors and its networks.; *4) Capabilities:* resources, competencies, and capacity necessary to adapt to new technologies and/or navigate in new markets successfully.

To illustrate how the combination of policies covering different dimensions is important to foster innovation and market development, consider for example the EPC[4] market in China, which has been growing fast since its introduction in 1998 and the industry output value increased from 1.8 billion CNY in 2003 to 415 billion CNY in 2017. According to the empirical results from a study conducted by Zhou et al. (2020), the linkage between policies and business innovations seems to have played a crucial role for the market growth. In this case the Chinese government combined incentive policies with legal measures and mechanisms to raise awareness among energy users and motivate them in practicing energy efficiency.

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[4]Energy Performance Contracting (EPC) is a form of 'creative financing' for capital improvement which allows funding energy upgrades from cost reductions. Under an EPC arrangement an external organization (ESCO) implements a project to deliver energy efficiency, or a renewable energy project, and uses the stream of income from the cost savings, or the renewable energy produced, to repay the costs of the project, including the costs of the investment. Essentially the ESCO will not receive its payment unless the project delivers energy savings as expected.

More specifically, the supportive policies (such as official guidelines, financial incentives, tax deduction, etc.) motivated the initial market development, which in turn enabled business to experiment and innovate to the point which the private sector itself started to undertake initiatives to address issues eventually left out of the policies (such as new business models and contracts models not initially foreseen), ultimately leading to a sustainable market growth.

Complementarily, understanding the networks dynamics may help to adjust the policies in order to foster collaboration, thus creating a virtuous cycle where the actors reinforce each other leveraging the whole ecosystem's capacity to innovate and develop markets.

2.2. The Helix Frameworks

In the previous sections we have reviewed the models of innovation systems with special focus on the geographic areas, technologies, and sectors that each one comprises, however, there is a model that according to the literature, is transversal to all the others, this is the *Helix Framework*. But, what does it mean by a *transversal model*? In the broadest sense of the word, it *crosses* or *intersects* with the other models, due to their commonalities, such as the actors and the importance of the relationships between them to generate innovation.

The major functions of a helix system are to generate, diffuse, and utilize knowledge and innovation. These are achieved through the competencies of knowledge generation and diffusion, hybrid organizations and entrepreneurs, and bringing together academia, industry, and government in discussion to reach a consensus in a knowledge-based economy. Regarding this, it is precise to highlight that the helix model simplifies the complexity of the relationships between the actors and defines three essential *elements* or *components*.

The *helix* name is explained due to the interaction between the components (specifically in the triple helix model: academia, government, and industry), where each one acts as a helix (similarly of a DNA chain). Thus, this relationship is not linear, but recursive, where eventually each component assumes the role of the other, a process also known as *hybridization*. Also, as indicated before regarding the *transversality* of the helix framework, this model is applicable to all the previous ones (NIS, RIS, TIS, etc.) in the search for an optimal innovation system. But this task is not easy to apply since the systems have different geographical classifications and challenges.

According to Cai (2014), in the development of a Regional Innovation System (using the helix framework), the role of innovation policy is crucial, because there are certain enabling conditions required to a successful triple helix system. The author argues that for the innovation system to be optimal, there must be a consensus on knowledge as the key to economic growth, a market-oriented culture with a sense of competition, as well as process-oriented knowledge management in the production of this. It is also essential to apply policies for the protection of intellectual property (IP) and to incorporate civil society in decision-making.

2.2.1. The Triple Helix

In innovation studies, it has always been a challenge to model the different processes that take place to generate an innovative environment, the *Triple Helix* is one of these frameworks that tries to capture the interactions between innovation stakeholders.

The Triple Helix model introduced by Etzkowitz and Leydesdorff (2000), examines the interactions of institutional spheres: government-industry-academia and establishes that in knowledge-based societies the universities play a central role in the innovation process. For instance, Etzkowitz (2003, p. 18) explicitly postulates the following:

> The interaction in university - industry - government is the key to improving the conditions for innovation in a knowledge-based society. Industry operates in the Triple Helix as the locus of production; government as the source of contractual relations that guarantee stable interactions and exchange; the university as a source of new knowledge, the generative principle of knowledge-based economies.

The author argues that in a knowledge-based society the university is evolving from being a secondary supporting institution providing research and training to becoming a leading institution. This change is explained by one of the fundamental characteristics of universities, as they have the students, which make for a flow-through of human capital; thus, it is potentially more innovative than any other knowledge institution.

Ranga and Etzkowitz (2013) propose 3 different ways to define the Triple Helix systems, however this study will not refer to these classifications in detail to avoid possible confusion. The definitions presented by the authors tend to be more conceptual and theoretical, moving away from the practical perspective required by those who apply the Triple Helix in the decision-making process related to the generation of innovation. Briefly, the model can be defined first according to its components, a wide range of actors present in each of the institutional spheres (academy - government - industry). Second, based on the relationship between the spheres such as collaboration and conflict moderation, networking, etc. Third, according to their functions that determine the system's performance and are defined as the competencies of the system's components. In other words, the Triple Helix model stands as a place for the generation and transfer of knowledge, attracting talent, promoting local development through entrepreneurship, and conducive to the exchange of ideas that promote the development of a society based on knowledge.

We have defined the Triple Helix system according to its components, relationships and functions, but what about the limits or boundaries of the model? To answer this question it is necessary to remember the process of *hybridization* that occurs when the three spheres play their traditional roles, but they also begin to take the role of each other. For instance, when a university begins to act similar to a business in helping to form firms, such as the Massachusetts Institute of Technology that created more than 30,000 firms since its creation; then the governments act as venture capitalists when they help to start new firms, such as the case of China, where the government represents over 40% of global venture capital investments, or the Silicon Valley which still leading the ranking representing 44% of the global venture capital investment (Dvorak and Saito, 2018). Finally, in the *hybridization* concept, industry typically begins to raise its training programs to a higher level and begins to act like a university. Not only in training, but also in research collaboration through open innovation models like the IMEC Affiliate Program from Belgium. Therefore, it is possible to infer that the boundaries between the spheres are blurred as a result of this process.

Ranga and Etzkowitz (2013) also describe two complementary perspectives of the Helix framework: the (neo-)institutional, which examines the growing prominence of the university among innovation actors and the (neo-)evolutionary. The (neo-)institutional perspective distinguishes between three main configurations in the positioning of the university, industry, and government institutional spheres relative to each other:

First, *The Statist Triple Helix*, where the government plays the lead role, driving academia and industry, but also limiting their capacity to initiate and develop innovative transformations. For example, the former Soviet Union, and some European and Latin American countries, in the era when industries were largely in the hands of the state. The main idea behind this version of the Triple Helix is that the country should keep its local technology industry separate from what is happening in the rest of the world. This version has been reformed over the years since it is evident that the economic failure to which it leads.

Second, *The Laissez-faire Triple Helix:* In this version, people are expected to act competitively rather than collaboratively in their relationships with each other. The role of the university is reduced to being a provider of basic research and trained people. There is limited interaction between university, industry, and government. The role of government in industry is expected to be limited to regulation mainly and as little as possible. However, at a general level, the government is expected to act only when the market cannot provide an activity, for example providing funds to universities to support research (Etzkowitz, 2003). To illustrate, consider the case of a highly developed economy as Switzerland, in which Hotz-Hart (2012) presents how the country boasts a high-income level and a hard currency. The author states that firms must be able to offer products and services to an international clientele interested in innovative and unique products where buyers are willing to pay a premium price. This requires a high capacity for innovation and an ability to generate innovations quicker and better than competitors. In the specific case of Switzerland, the state tends not to get involved in the direction of technological development at all. The market is responsible for generating innovations. If necessary, the business environment is shaped to create a climate that is as conducive to innovation as possible.

In this case study about Switzerland, for most of the cases, policies to promote innovation are implicit (only general guidelines). Thus, when actors are setting policy objectives, innovation is not considered the main goal. For example, promotion of innovative performance is subsumed in goals such as growth, research excellence, energy efficiency, or sustainability. Innovation policy is operated from a fragmented system in which various actors pursue their own agendas. There is no support or integration, for instance, by means of an advisory body or an innovation council. In addition, the private sector, headed by several major companies, also spends large sums of money on R&D, which is a sign of strength. Thanks to such cooperation projects, Switzerland has acquired substantial skills and know-how. To develop their technological basis, Swiss firms are sourcing technology worldwide with great success. Knowledge components are adopted from abroad and combined with home-made components or are transferred to expand the knowledge base in Switzerland. According to this example there is no major interaction or coordinated work between Industry - Academia - Government, each one acts by following their own objectives.

Third, *The Balanced Triple Helix*, that was born by the increase in the interaction between academia, industry, and government as equal partners, and the new developments of innovation strategies as a result of this cooperation, which stand as the core of the Triple Helix model of economic and social development. In this sense, the model even becomes a platform for the formation of *institutions*, for the creation of new organizational formats to promote innovation such as incubators, science parks, and venture capital firms (Etzkowitz and Leydesdorff, 2000).

A clear example of this balance within the triple helix is illustrated in the case of Shenzhen (China) on its trajectory to become a Special Economic Zone since 1996. Liu and Cai (2017) states that the Triple Helix model in Shenzhen is characterized by the decreasing control of central government and the increasing balanced interaction of local government, industry, and academia. The central government loosened control over the Shenzhen while shifting the focus to other less developed regions and international affairs.

On other hand, the local government of Shenzhen, the industry, and academia built interactive linkages with each other. Local government created a favorable institutional environment to attract high-tech industries and universities elsewhere for local development. The industry, with emerging influences of domestic enterprises, conducted R&D to upgrade their production and innovation capability. The universities engaged actively in technology transfer and the start-up of companies.

According to Liu and Cai (2017), during the process of Shenzhen's development, domestic industries learned advanced technologies through collaboration with foreign enterprises and held increasing shares in the domestic and international market. Meanwhile, to meet the increasing intellectual requirement, the local government first established a local university and then attracted research universities elsewhere to the area through the initiatives of science parks, virtual campuses, and university towns. While the local university focused mainly on teaching and training, the various research universities built intensive linkages with the industry by setting up research labs, inventing patents, conducting technology transfer, and incubating high-tech firms.

In Shenzhen's example it is possible to appreciate that the Industry - Academia - Government act in a more coordinated and balanced manner, the actors don't exceed their influence over other one. Thus, they aim to work harmoniously to get better results fostering innovation and technological/scientific development.

On the other hand, the (neo-)evolutionary perspective states that in addition to performing its traditional tasks, each of the spheres *takes on the role of each other*. This means that each institution maintains its primary role and distinctive identity and assumes some of the capacities of the other. This dynamic increases the probability that each sphere will become a source of innovation and serve as a support for the creativity that emerges in other spirals.

In fact, one of the main differences between a National Innovation System (NIS) and the Triple Helix is observed in the range of operation of each one. While the NIS operates along a single axis, that is, it only plays its traditional role, the Triple Helix operates along two axes, where in addition to playing its traditional role, it also plays new roles (belonging to the other spheres).

2.2.2. The Quadruple Helix

In recent years, the literature also criticizes the Triple Helix model, pointing out its authors have paid little attention to national, political, and socioeconomic contexts that could affect innovation activities (Balzat and Hanusch, 2004). In line with the above, Chang López (2020) argues for the model to work, the context of each country must be considered, they must have a macro regulatory framework that involves modifying the political constitutions of the countries, at the meso level, reforming industrial, economic, tax and higher education policies, and at the microenterprise level and beneficiary families. All these modifications or reforms must be consistent with the political-economic model and with the idiosyncrasies of the population of each of the countries. This is how this model has evolved trying to respond to criticism and has incorporated a fourth helix represented by the civil society. Additionally, Carayannis and Campbell (2009) suggest adding a *fourth helix* that they identify as the *media-based and culture-based public*. They argue that knowledge and innovation policies and strategies must acknowledge the important role of the *public* for a successful achieving of goals/objectives due to the triple helix insufficiency in long-term/sustainable growth.

However, what is specifically the role of the public or civil society in economic development? To understand it, consider the case of the Värmland region in Sweden, in which Roman et al. (2020) studied the "Genius Loci Project (2008 – 2011)", an initiative which aim was to develop a growth-creating model for the region and its municipalities, strengthen existing companies, and stimulate entrepreneurship by creating new methods for participation and cooperation between different groups (researchers, enterprises, the public sector, associations, and individuals). In this case, methods were developed by focusing on local assets, local talents, local traditions, and trust. The role of the civil society in the project took different forms, from receiving training and information and participating in local development activities to engaging in dialogue with other actors, including universities, research institutes, companies, and the public sector, and finally participating in the co-creation of the local growth model. The three-year-long EU co-funded project involved 4500 people in different workshops, meetings, events, study trips, and new meeting spaces. The main outcomes of civil society participation increased openness and collaboration between the different Quadruple Helix actors. The project succeeded in attracting new actors for local/regional development activities and in increasing understanding between different stakeholder groups.

2.2.3. The Quintuple Helix

A fifth helix can be found in the literature, which formally responds to social demands that fight against global warming as the biggest problem that humanity faces in the 21st century. In this regard, sustainable development as an economic model proposes a real alternative to cope with this issue. It states a balance between the three pillars that sustain it: economic, social, and environmental. In other words, none of the capitals can be on the other, but they must complement each other since the total result must be positive. Economic and social development should not be detrimental to the environment, in this sense the role of knowledge and innovation as engines of development is fundamental. Hence, Carayannis and Campbell (2010) add a quintuple helix, the *natural environment*. Thus, representing a framework for transdisciplinary (and interdisciplinary) analysis of *sustainable development* and *social ecology*, focusing on the interaction, co-development and co-evolution of society and nature, in combination with knowledge production and innovation.

In more recent studies (Carayannis et al., 2012) point out that the goal and interest of the Quintuple Helix is to include the natural environment as a new subsystem for knowledge and innovation models, so that *nature* becomes established as a central and equivalent component of and for knowledge production and innovation. Thus, according to the authors, the Quintuple Helix, thereby, visualizes the collective interaction and exchange of knowledge in a state (nation-state) by means of the following five subsystems (i.e., helices): education system, economic system, natural environment, media-based, and culture-based public (also civil society), and the political system.

By using the Triple Helix model of innovation considering civil society and the natural environment, it can represent a facilitating mechanism for economic and social development, and set the foundations for rapid social development, when political and social agreements are established under principles of equity and transparency. In turn, the Quintuple Helix proves its ability to contribute to social sustainability when the components work on solutions (including social sciences and technologies) to issues raised by industry, society, or public administrations. This model promotes systemic, organizational, and social innovations that include new social conventions and channels for interaction, which is why it is proposed as a strategy to increase social capital and close technological gaps (Luengo-Valderrey et al., 2020).

As a compelling example, it is well known in the literature that nowadays there exists a global concern on climate change, in which consumers and citizens are worried about the environmental conditions of the planet since it directly affects the existence of the human species in the future. So, in this case, the actions of civil society may push the work of governments in designing strategies to achieve a green economy and industries who also respond to these changes in demand developing products and services with low carbon footprint and that they generate the least possible environmental impact. If companies do not consider the demands and concerns of civil society, they put their reputation and profitability at risk in the long term. The same happens with governments, which are exposed to dismissal and non-continuity of their mandate. In essence, the power of civil society focuses on granting legitimacy to institutions.

To conclude, this literature review has repeatedly cited the case of China and its impressive economic and innovation development that the Asian giant has experienced in the last 20 years. In the global innovation landscape, China has climbed from the 26th place in 2016 up to the 14th in 2019, and it is the only middle-income economy among the top 30 global economies. It is possible to identify that there has been significant progress made by China in its innovation indicators from various aspects, ranking top in terms of domestic patents, industrial design, original trademark, thigh-tech and creative products exports, etc.; thus not by coincidence China is entering into a new stage of development for innovation (Deloitte, 2019). For those reasons, the next sections dedicated to the empiric research will be focused on understand how China has presented such impressive evolution in innovation matters in recent years. It may bring light to how academia, industry, and government have evolved their roles and dynamics toward innovation. For this reason, the empirical research will explore China's innovation ecosystem carrying out historical analysis of events, policies, and data covering the last 20 years of China's innovation ecosystems.

3. Methods

As stated in the literature review from this study, innovation does not happen by itself, nor does it happen in a simple, predictable, and linear environment. Overall, studies on innovation and its ecosystem are not an exact science; still, they are evolving due to the constant interaction and increasing interest among the different stakeholders that participate in the knowledge creation process. For this reason, to understand how China has evolved its innovation ecosystem and achieved a global leadership position in innovative capacity, this study is based on the method of *historical research* in an attempt to "systematically recapture the complex nuances, the people, meanings, events, and even ideas of the past that have influenced and shaped the present" (Berg and Lune, 2012, p. 305).

First, this research explores how China has changed its overall economic landscape, its openness to international trade, and its intellectual property regime since the early 1980s. The aim is to present the main events and characteristics which shaped the country's profile regarding the intensity of inflow and outflow of knowledge and technology.

Second, based on the frameworks and findings from the literature review, this study analyses China's innovation ecosystems on the national, sectorial, and regional dimensions. These analyses are done through the perspective of the Triple Helix, combining the gathering of historical events and more recent data as from the past 20 years to illustrate the up-to-date developments at the China's innovation ecosystems.

The aim of the suggested approach is to answer the following research questions:

1) How are China's national, regional, and local governments organized to foster innovation and technological/scientific development? Which are their main institutions and policies?
2) How has China's academic landscape and performance evolved, and which programs are in place to foster R&D collaboration within the industry?
3) How has China's industry evolved in terms of R&D investment, new products development, and international trade?
4) Which are the main differences within the national, regional, and sectorial dimensions of China's innovation ecosystems?
5) Which are the main results that China has achieved in terms of patents/inventions and attraction of foreign trade investment?

The main source of data and events for this study are the official websites, online platforms, and reports from the Chinese government and institutions (such as China Statistical Yearbooks, the National Bureau of Statistics of China, The State Council of the People's Republic of China, the Ministry of Science and Technology, the Ministry of Education, the Ministry of Industry and Information Technology). Furthermore, additional sources used in this study include complementary scientific articles (other than the ones explored in the literature review), websites, statistical data, reports, and white papers from international institutions such as Chambers of Commerce, the European Commission, the Organisation for Economic Co-operation and Development (OECD), among others.

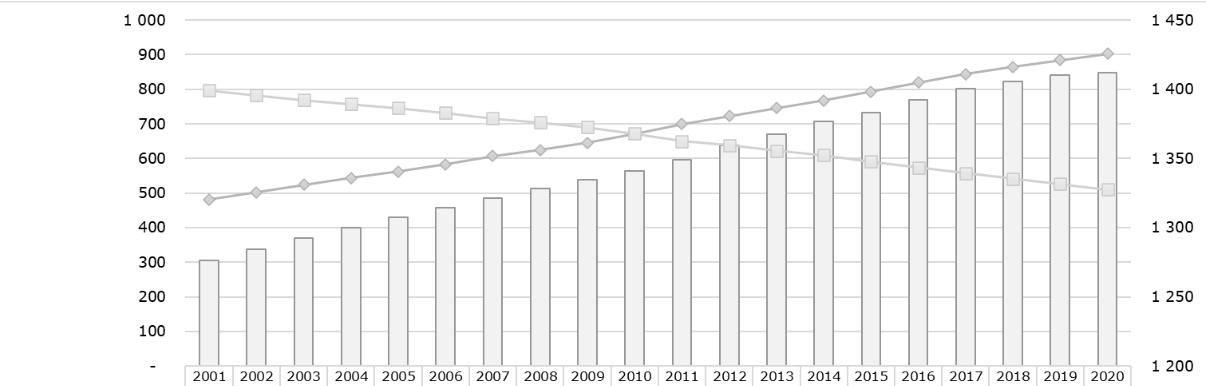
4. Results

4.1. China’s Country Profile

Nowadays, China is a country that stands out for positioning itself among the global leaders in technologies such as: e-commerce, artificial intelligence, fintech, high-speed trains, renewable energy, and electric cars. It also stands out for its important innovation hubs in Beijing, Shanghai, and Hong Kong that are part of the top 10 innovation hubs outside US (KPMG, 2020). Being a middle-income economy, it still enjoys economic growth ranging between 6% to 7% per year (World Bank, 2019), however, this was not always the case. The remarkable evolution of the Asian giant's economic development dates back four decades ago, when the population was approximately 1 billion people and the growth base was associated with resource-intensive manufacturing, exports, and low-paid labour. The consequences of this form of development, which led a sustained growth of almost 10% of GDP per year for four decades, are characterized by notorious social and environmental imbalances (World Bank, 2019).

One of the biggest challenges that China is facing nowadays refers to reducing imbalances through profound changes in the structure of the economy from low-end manufacturing to high-end manufacturing and services. Nevertheless, on the way to ensuring sustainable and high-quality growth, it is a priority to consider the greenhouse gas emissions that this entails, so it is essential that the transition to a new growth model is with high respect for the environment, above all to somehow amend the polluting legacy of the previous model. In addition, the rapid growth and aging of the population that already reaches 1,395 million inhabitants with a strong shift in concentration to the urban areas (see Exhibit 02) are other fundamental points to consider to address these challenges.

Exhibit 02 – China’s Population year-end (million persons)



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total Population	1 276	1 285	1 292	1 300	1 308	1 314	1 321	1 328	1 335	1 341	1 349	1 359	1 367	1 376	1 383	1 392	1 400	1 405	1 410	1 412
Urban Population	481	502	524	543	562	583	606	624	645	670	699	722	745	767	793	819	843	864	884	902
Rural Population	796	782	769	757	745	732	715	704	689	671	650	637	622	609	590	573	557	541	526	510

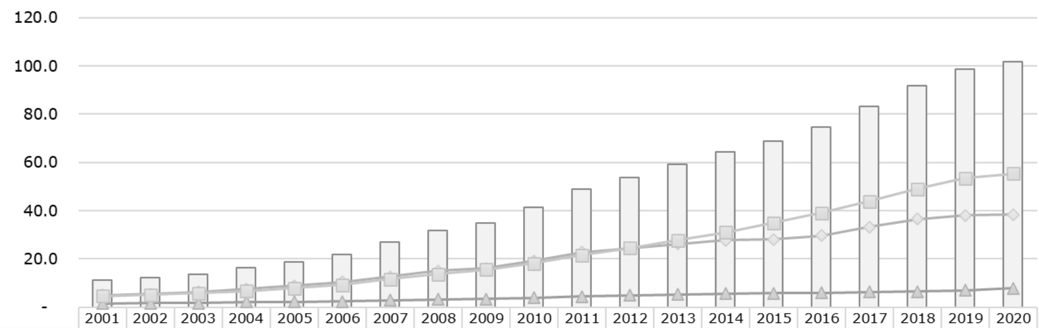
Source: *data extracted on 06 July 2021 from National Bureau of Statistics of China.*

Note: *Figures from 2000 and 2010 are the census year estimates; the rest of the data covered in those tables have been estimated on the basis of the annual national sample surveys of population.*

History is a faithful witness that many times, from an economic-political point of view, in order to evolve it is necessary to face turbulent periods, as evidenced by the great social revolutions in France, Russia, and industrialism in the case of England. China is no exception, after the death of Mao Zedong in 1976, the country faced a series of unprecedented changes, profound social and economic reforms that were the foundations of subsequent economic development. In 1978 Deng Xiaoping assumed as maximum leader of the Chinese Communist Party and with it, as supreme leader of the Popular Republic of China. Its influence has been gravitational in Chinese society, since due to its eminently capitalist vision, it promoted the opening of the country towards international markets and established economic and technological development as the new priorities of the regime (Manzoor and Sajid, 2018).

Regarding public policies, China developed a document called *The Five-Year Plan*, which contains the guidance for the country's economic objectives to be implemented during five year cycles. The first five documents (covering from 1953 to 1980) had a notorious Soviet influence, which was evidenced in centralized economic planning, agricultural groups, and state property. However, the Soviet model did not perform well due to economic conditions in China. Hence, the arrival of Deng Xiaoping to power brought a 180-degree turn on the plans, his vision of a modern and technological China was printed in the National Program of High Technology Innovation and Development, also known as The 863 Program. This initiative was born to face the challenges related to new technologies and competition at a global level, where its main objective was to accelerate the development of high-tech industries in China, thus also laying the foundations for subsequent policies. The 863 Program was planned to be executed and implemented during the next three five-year plan periods, and in the tenth five-year plan (2001-2005), the Chinese State Council approved the continuity of the 863 Program for the following three cycles, thus playing a fundamental role to date. This proves the coherence and consistency of Chinese policies for innovation and development. For instance, in the last two decades China has reached an impressive tenfold growth of its annual Gross Domestic Product (GDP) with a strong rise of its tertiary industry as shown in the Exhibit 03.

Exhibit 03 – China's Gross Domestic Product (trillion yuan)



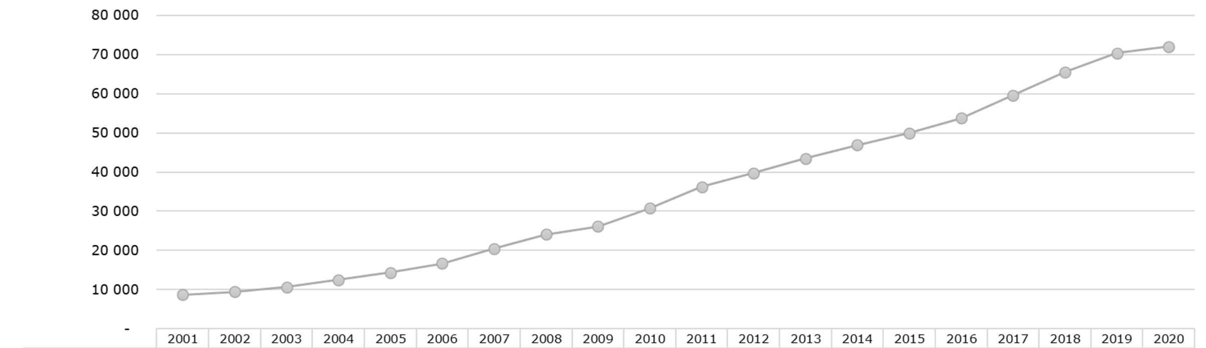
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
GDP	11.1	12.2	13.7	16.2	18.7	21.9	27.0	31.9	34.9	41.2	48.8	53.9	59.3	64.4	68.9	74.6	83.2	91.9	98.7	101.6
Primary Industry	1.6	1.6	1.7	2.1	2.2	2.3	2.8	3.2	3.4	3.8	4.5	4.9	5.3	5.6	5.8	6.0	6.2	6.5	7.0	7.8
Secondary Industry	5.0	5.4	6.3	7.4	8.8	10.4	12.7	15.0	16.0	19.2	22.7	24.5	26.2	27.7	28.1	29.5	33.2	36.5	38.1	38.4
Tertiary Industry	4.6	5.1	5.8	6.7	7.7	9.2	11.6	13.7	15.5	18.2	21.6	24.5	27.8	31.1	35.0	39.1	43.8	49.0	53.5	55.4

Source: *data extracted on 06 July 2021 from National Bureau of Statistics of China.*

Note: *Data are calculated at current prices. The classification by the three strata of industry is based on the Regulation on the Classification by Three Strata of Industry revised by the National Bureau of Statistics in 2018. The primary industry refers to agriculture, forestry, animal husbandry and fishery industries (except support services to agriculture, forestry, animal husbandry and fishery industries). The secondary industry refers to mining (except auxiliary activities of mining), manufacturing (except repairs for metal products, machinery and equipment), production and supply of electricity, steam, gas and water, and construction. The tertiary industry refers to all other industries not included in primary or secondary industry. According to China's regulations on the GDP revisions and international practice, systematic revisions are made on the GDP figures for 2018 and earlier years with the data from the fourth economic census available.*

Furthermore, not only the absolute value of China’s GDP has increased substantially during the last 20 years, but the GDP per capita has also improved (see Exhibit 04), thus representing China’s improvement in its standard of living and how much citizens may benefit from the economy.

Exhibit 04 – China’s Gross Domestic Product per Capita (yuan)



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Per Capita GDP	8 717	9 506	10 666	12 487	14 368	16 738	20 494	24 100	26 180	30 808	36 277	39 771	43 497	46 912	49 922	53 783	59 592	65 534	70 328	72 000

Source: *data extracted on 06 July 2021 from National Bureau of Statistics of China.*
Note: *Data are calculated at current prices.*

4.2. China’s Intellectual Property Regime

Along with explaining the national context of the Chinese innovation ecosystem, it is important to understand the treatment given to Intellectual Property (IP) rights in the country. Thus, the purpose of this section is to explain the evolution of IP regulations, the degree of compliance with the rules, and the actual enforcement of these in the People's Republic of China.

IP rights are related to the economic development of a country since it can foster or hinder the attraction of Foreign Direct Investment (FDI) and shape the intensity of technology and knowledge transfer. For instance, according to a study carried out by the World Bank (1994), evidence is shown that *the strength or weakness of a country's IP system and protection seems to have a substantial effect, particularly in high-technology industries*. This study will focus only on the most significant facts about the process of China’s IP evolution, for instance, according to a study made by Chen (2015), China had four waves of IP development from 1973 to 2014 (the Figure 02 summarizes the main events of it).

According to Chen (2015), the four waves were: 1) *IP Fever*, which began in the period where Trademark and Patent Laws were adopted, including China joining the *WIPO (World Intellectual Property Organization); 2)* China was included in the watch list of *The Office of the United States Trade Representative (USTR)* in 1989, which evaluates the adequacy and effectiveness of U.S. trading partners’ protection and enforcement of intellectual property rights, and China adopted the Copyright Law in 1990 including a separate set of computer software regulations followed in 1991, followed by the adoption of the *MOU (Memorandum of Understanding Between China and the United States on the Protection of Intellectual Property)* in 1992 to avoid a trade war; 3) *The Wave of Improvement*, begins in 1995 when China becomes one of the signatory countries of the *TRIPS agreement (Trade-Related Aspects of Intellectual Property Rights)*, which stands as the most important measure of international trade and intellectual property; 4) *The Enforcement Wave*, started in 2001 when China was admitted at the *WTO (World Trade Organization)* by complying with the TRIPS agreement and committing to engage in global competition according to rules of the WTO.

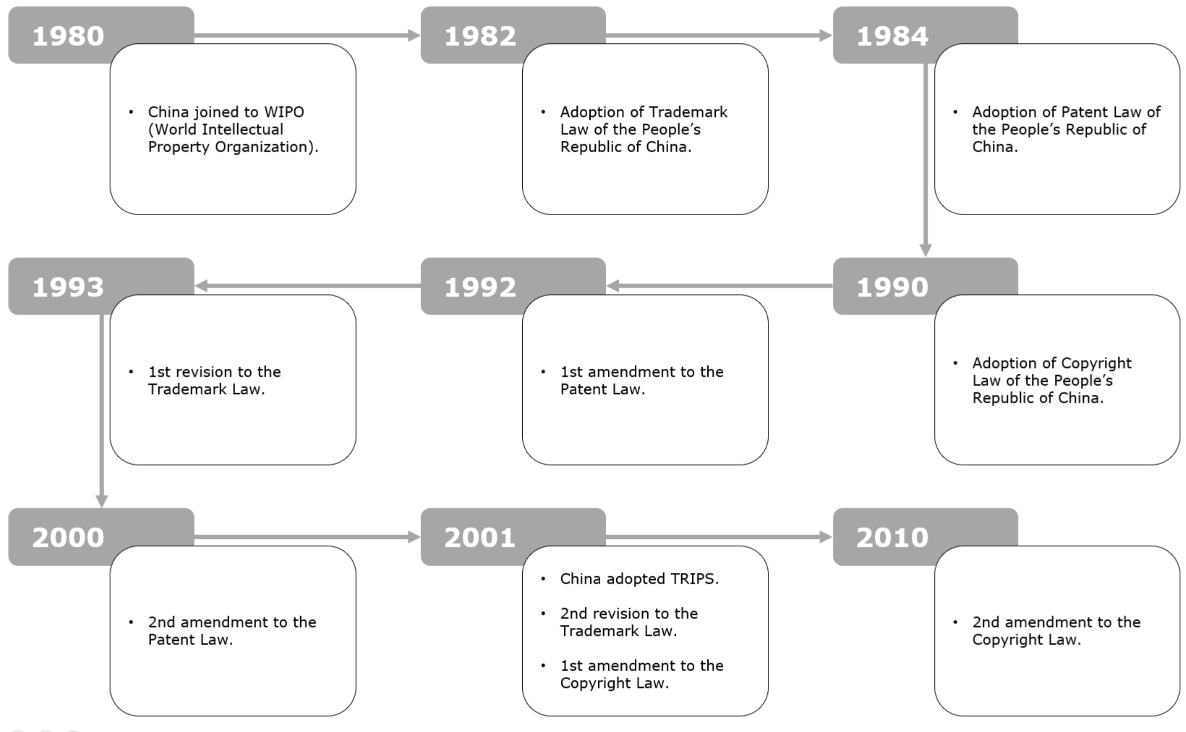


Figure 02: *China's IP Timeline*

The intention to improve regulation by the Chinese government cannot be ignored, however, despite the efforts of the state enacting laws and annexing international treaties, this does not imply an effective protection of Intellectual Property Rights. For this to happen it is necessary, not only that the law exists, but also that it is properly complied and effectively enforced. The latter is what China is most criticized for, especially by the United States. A concrete example of this situation is illustrated by Hickey et al. (2020, p. 1):

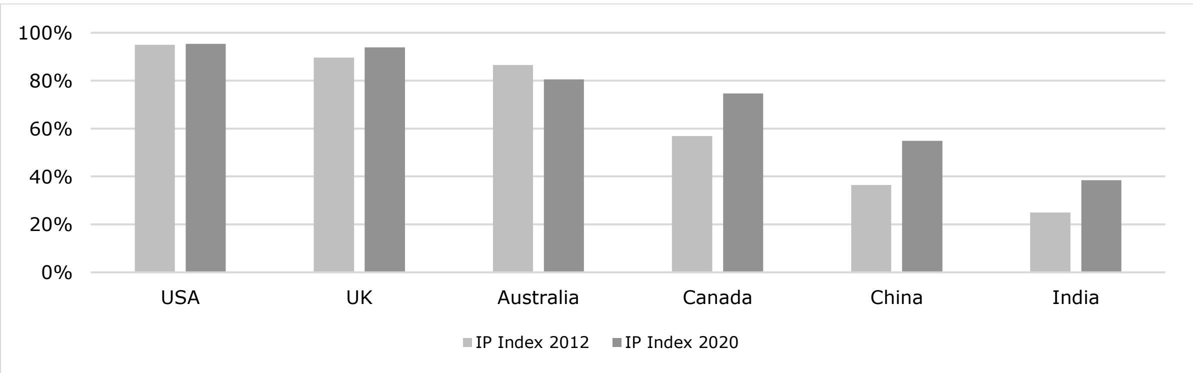
> On August 18, 2017, the U.S. Trade Representative (USTR) initiated an investigation under Section 301 of the Trade Act of 1974 (Section 301) into whether acts, policies, and practices of the Government of China related to technology transfer, intellectual property, and innovation were unreasonable or discriminatory, and burdened or restricted U.S. commerce. On March 22, 2018, the USTR (US Trade Representative) concluded its investigation, finding that four Chinese policies and practices violated Section 301: (1) use of foreign ownership restrictions and administrative licensing requirements to pressure technology transfer from U.S. companies to Chinese entities; (2) IP licensing restrictions that discriminate against foreign entities; (3) systematic investment in or acquisition of U.S. companies to acquire targeted technologies; and (4) unauthorized cyber intrusions into U.S. networks to obtain IP and other confidential business information.

History and facts show that there is no question that much still needs to be done in order to improve the effective application of IP laws in China. On the other hand, analysing the phenomenon of Chinese economic growth and innovation intensity in the last twenty years, it may give the perception that the IP rights protection does not directly affect the country's performance. For instance, despite the evidence indicating that the IP system is not strong enough when it comes to law enforcement, China has become a giant in terms of innovation and economic development.

However, to *demystify* the previous assumption around a possible low implication of IP rights on China's economic and innovative development, Ang et al. (2014) examined IP rights enforcement in different provinces in the country and found out that high-tech firms in provinces with better IP rights enforcement have greater access to external debt, higher investment levels in R&D, and better tangible results (such as patents and new product sales) and therefore serves as a factor to stimulate economic growth; so their research shows that IP rights enforcement does actually matter in China.

According to the reports published by the Global Innovation Policy Centre (2021), the IP evolution of China has not been exempted of difficulties, however, it has been improving after all. In the IP Index Report published in 2012 China had a score of 9.13 out of 25, quite far below than other big economies such as US and UK whose lead the ranking. Overall, China's performance was weak compared to the other countries, especially in the *enforcement category* (which measures the prevalence of IP rights infringement, the criminal and civil legal procedures available to rights holders, punishment rates, and the authority of customs officials to carry out border controls and inspections). Nowadays, the scenario is different, according to the IP Index Report, China has improved its score extraordinarily going from 36.5% of the total available score in the first edition of the IP Index 2012 to 54.8% in the most recent one, as summarized on the Exhibit 05 The incredible growth is due the positive reforms implemented in China aiming to create a most suitable environment for innovation.

Exhibit 05 – IP Index Report Comparison



Source: *our analysis, based on scores from the Global Innovation Policy Centre from 2012 and 2020.*

Note: *The methodology related to the score calculation changes from 2012 to 2020, so to enable comparability between the years, the scores achievement are converted to percentage versus maximum.*

Corroborating with the findings from the *Global Innovation Policy Centre*, another important publication from the *Property Rights Alliance* also shows improvements from China's property right index from 2007 to 2020 as shown on the Exhibit 06. It is important to notice however, that the regional and global ranking do not improve due to other countries also catching up on their score.

Exhibit 06 – China's International Property Rights Index Evolution

Year	Score	Annual Change	Global Rank	Regional Rank
2007	4.419		45	9
2008	4.400	-0.019	46	10
2009	4.683	0.283	69	11
2010	5.087	0.404	64	11
2011	5.500	0.413	59	11
2012	5.500	0.000	57	10
2013	5.500	0.000	56	10
2014	5.500	0.000	48	8
2015	5.389	-0.111	52	9
2016	5.408	0.019	55	9
2017	5.712	0.304	52	9
2018	5.904	0.192	52	9
2019	6.033	0.129	49	9
2020	6.045	0.012	49	9

Source: *Property Rights Alliance 2021.*

Furthermore, as shown on the Figure 03, China's IPRI results from 2020 are not better due to issues related to legal and political aspects (such as the assessment of the country's judicial independence, rule of law, control of corruption, and political stability).

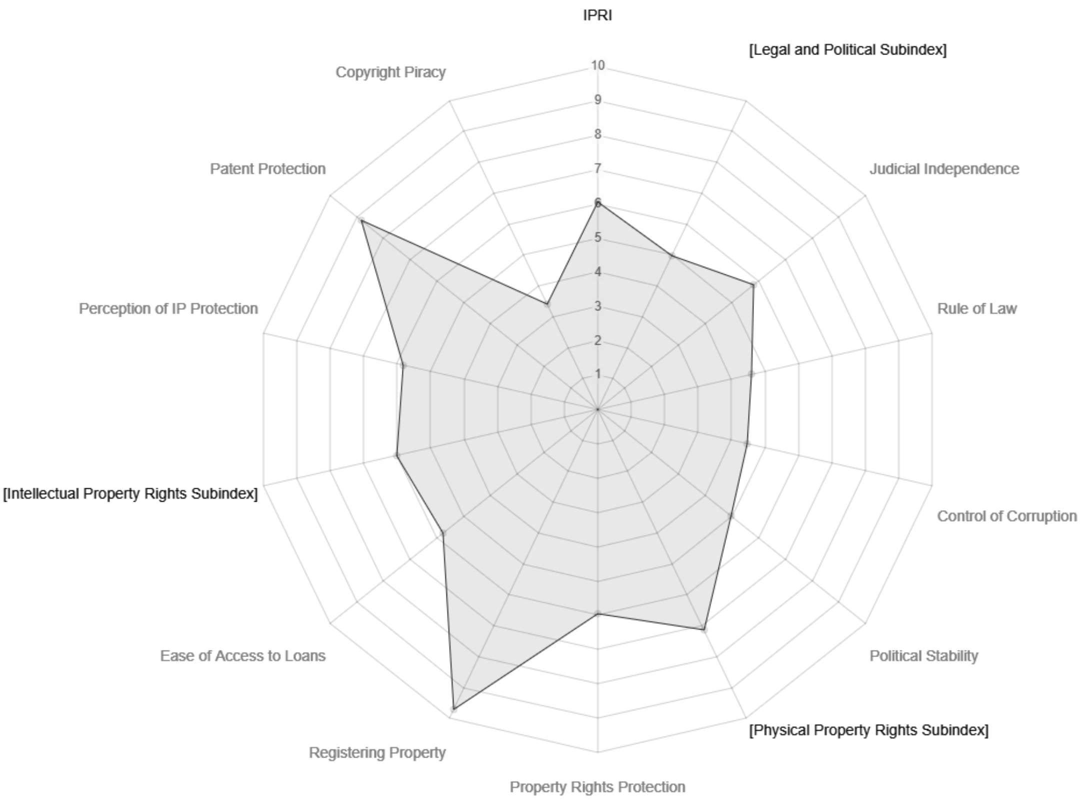


Figure 03: *China's IPRI from Property Rights Alliance 2020.*

Nowadays, after four bilateral US-China agreements on IP rights protection (1989, 1992, 1995, and 1996) and China's admission at the WTO, piracy in China is no longer primarily the result of the Beijing government's own actions. However, the underlying problem is linked to the fact that Beijing has failed to ensure that its international laws and obligations are adequately and effectively fulfilled. According to Massey (2006), the responsibility for this rests with the Chinese provincial authorities, which benefit economically or politically from the profits of piracy or, often turn a *blind eye* to the powerful local interests that do so. On the other hand, the institution who should control this situation is the judicial system, which is often not capable of imposing dissuasive sanctions against those who violate the rules, specifically piracy.

4.3. China's National Innovation System (NIS)

This section explores the main characteristics and policies of China's national ecosystem for the promotion and development of science, technology, and innovation in the last 20 years. Specifically, the purpose of this section is to understand the roles and actions, the organization, the polices, and the inputs and achievements around the Triple Helix within the national context of China (namely, the relationship within Government, Academia, and Industry).

To begin with, it is important to contextualize how the latest *Five-Year-Plans* guidelines have evolved, since these plans represent a foundation for China's goals and measures regarding innovation and economic development. Starting from the tenth Five-Year-Plan (2001-2005), it is worth mentioning that it continues with the policies implemented in previous periods, faithful to the capitalist gaze of Deng Xiaoping, pushing for the economic opening to foreign trade, the development of science, technology and education as a national priority, and the selective stimulus promoting the development of new high-tech industries. For instance, one recurrent goal has been to not merely develop incremental innovations, but to make great discoveries in key technological fields, and then applying these new technologies to production and industries modernization.

On top of the major objectives and guidelines addressed by all Five-Year Plans (such as the targets related to gross domestic product, total national population, resources consumption, educational level of population, jobs creation, among others) each new plan includes evolutionary guidelines related to specific development areas as summarized on the Exhibit 07.

Remarkably, the 13th Five-Year Plan emphasizes priorities related innovation-driven development, cyber economy, and modern infrastructure networks. These priorities were embedded into other development areas at previous Five-Year Plans, but as from 2016 these dimensions received dedicated attention into China's national guidelines and policies.

It is not the objective of this study to analyse the Five-Year Plans in detail, but it is important to present an overview of the main priorities over time because as previously mentioned, these plans represent the foundation of China's policies and programs for national development, thus having direct impact on the efforts towards innovation, scientific and technological development, as well in how the country fosters knowledge sharing, international trade openness, and shapes the roles and responsibilities, and autonomy of all players within the innovation ecosystem.

Exhibit 07 - China's Five-Year Plans Development Areas

Priority Guidelines	11th Five-Year Plan (2006-2010)	12th Five-Year Plan (2011-2015)	13th Five-Year Plan (2016-2020)
Manufacturing Industry Development			
Accelerate the development of High-Tech Industry	X		
Vigorously develop equipment manufacturing industry	x		
Optimize the development of Energy Industry	x		
Adjust raw material industrial structure and distribution	x		
Promote the lvel of light and textile Industry	x		
Actively push forward informatization	x		
Improve and promote manufacture		x	
Accelerate the reform of energy production and utilization mode		x	
Construct comprehensive transportation system		x	
Comprehensively improve the informatization level		x	
Promote the development of marine economy		x	
Foster and develop strategic emerging sectors		x	x
Develop China into a Manufacturing Powerhouse			x
Regional Coordinated Development			
Implement the overall regional development strategy	x	x	
Promote the sound development of urbanization	x	x	
Implementing the strategy of major function regions		x	
Implement the master strategy for regional development			x
Promote the integration of Beijing, Tianjin, and Hebei			x
Develop the Yangtze Economic Belt			x
Support the development of special regions			x
Widen space for the Blue Economy			x
Science, Education and Human Resource Development			
Accelerate Scientific and Technological Innovation and leap-over	x		
Give priority to education development	x		
Reinvigorate China through Human Resource Development	x		
Strengthen the capability of technological innovation		x	
Speeding up the reform and development of education		x	
Establish grand high-quality talent teams		x	
Mutual Benefit and Win-Win Opening Strategy			
Accelerate the change of foreign trade growth model	x		
Improve the auality of introducing Foreign Investment	x		
Actively conduct international economic cooperation	x		
Improve regional opening up pattern		x	
Optimize foreign trade structure		x	
Coordinate 'Bring in' and 'Going Out'		x	
Participate in global economic governance and regional cooperation		x	
Improve the strategy and new system for opening up			x
Move forward with the Belt and Road Initiative			x
Participate in Global Economic Governance			x
Assume international responsibilities and obligations			x
Innovation-Driven Development			
Ensure innovation in Science and Technology takes a leading role			x
Encourage public Startups and Innovations			x
Establish innovation-promoting institutions and mechanisms			x
Prioritize Human Resource Development			x
The Cyber Economy			
Build ubiquitous, efficient Information Networks			x
Develop modern Internet Industries			x
Implement the National Big Data Strategy			x
Strengthen Information Security			x
Modern Infrastructure Networks			
Develop better modern comprehensive transportation systems			x
Build a modern energy system			x
Strengthen water security			x

Source: *National Government of People's Republic of China 2021.*

4.3.1. National Government and Policies

The government of China formulates and facilitates the implementation of strategies and policies for innovation-driven development through the *Ministry of Science and Technology*. The organization coordinates the development of the national innovation system and the reform of the *National Science and Technology Management System*, aiming to encourage technological innovations, improve the R&D system, and enhance the innovation capabilities of enterprises (MOST, 2021). For instance, beginning in the 1980s, China formulated several programs for scientific and technological research and development, aiming to improve the country's competitiveness in science and technology in the 21st century (China Internet Information Centre, 2021). The Figure 04 summarizes the five key programs that have formed the main body of the state initiatives for science and technology development, these programs will be further explained in this section.

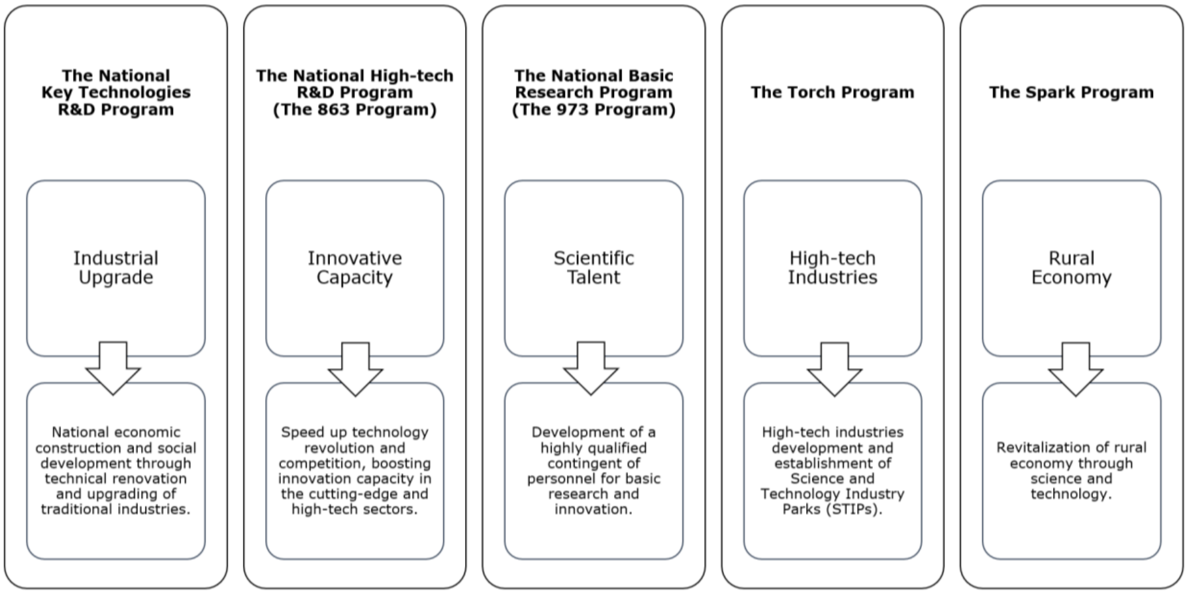


Figure 04: *China's main national programs of Science and Technology Development.*

The *National Key Technologies R&D Program* is the first national science and technology (S&T) program in China, initiated in 1982 and implemented through 4 five-year plans. The main objective was to address issues related to national economic construction and social development through technical renovation and upgrading of traditional industries, while also boosting sustainable development and increasing China's innovative capacity. The program focused on projects related to sustainable agricultural development, IT applications for traditional industries, technologies and equipment for clean energy, intelligent traffic system, textile post-treatment, informatization process for the financial sector, modernization of traditional Chinese medicine, environmental protection and rational utilization of resources, such as water, oil, gas and solid minerals (MOST, 2021). Since 1982, more than 500 projects have been approved with 100000 items of achievement in scientific research after four five-year plans had been completed and, by the end of 1999, the projects produced a gain of RMB 153.4 billion to the nation. The legacy of this program still reflects on recent improvements in basic conditions of transport and energy production. For instance, according to the China Statistical Yearbook (2019), from 2001 to 2018, the country's length of transport route has increased 294%, while the energy production from 2000 to 2018 has increased 172%.

The *National High-tech R&D Program (The 863 Program)* was created in 1986 to cope with global challenges of technology revolution and competition, aiming to accelerate China's high-tech development. It was initially implemented during three successive five-year plans, and in 2001, the Chinese State Council approved the continued implementation of the program, which ended in 2016. From 2001, the goal of this program was to boost innovation capacity in the cutting-edge high-tech sectors and achieve breakthroughs in key technical fields for China's economy and national security. For instance, the program supported several projects related to information infrastructure, biotechnology, pharmaceuticals, advanced agricultural technology, advanced materials technology, advanced manufacturing and automation, energy, and environmental technology (MOST, 2021).

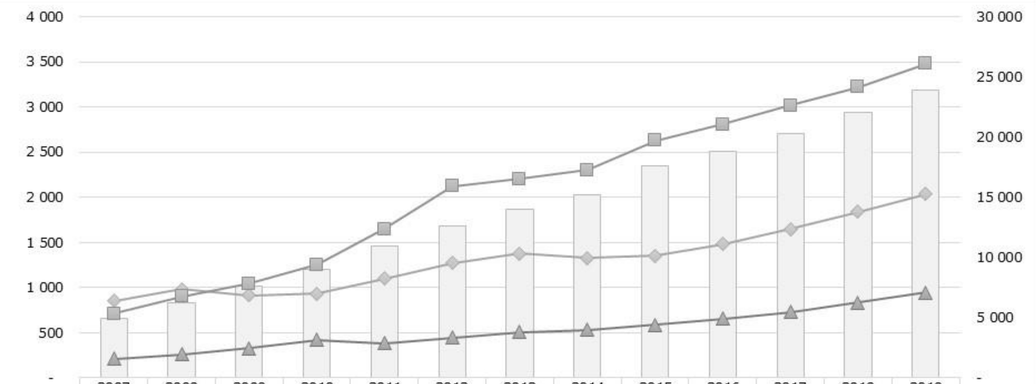
The *National Basic Research Program of China (The 973 Program)* was established in 1997 as a backbone of S&T and economic development, being considered as a driving force for inventions and new technologies, aiming to achieve breakthroughs in economic and social sectors. The strategic objective of the program is to mobilize China's scientific talents in conducting innovative research on major scientific issues in agriculture, energy, information, resources and environment, population and health, materials, and related areas. One of the pillars of this program has been its people-oriented approach, aiming to develop a highly qualified contingent of personnel for basic research and innovation at universities. The program supports young and middle-aged scientists, encouraging the exploration of new research fields and guiding them in conducting innovative research. Additionally, applying a combination of government decisions and expert consultation, providing high-level advisory from senior experts in charge of consultancy, assessment, and supervision of the program to ensure its scientific, democratic, and fair implementation (MOST, 2021).

The *Torch Program* was established in 1988, and it is considered China's most important program of high-tech industries, organizing, and carrying out projects to develop high-tech products with high standards and strong economic benefits in domestic and foreign markets. The program has been promoting the construction of the *Science and Technology Industry Parks (STIPs)* and focusing on projects related to new technological fields, such as new material, biotechnology, electronic information, integrative mechanical-electrical technology, and advanced and energy-saving technology (China Internet Information Centre, 2002). The central government has approved 53 development zones at the national level, resulting in clusters of high-tech industries in the coastal, frontier, border, and inland cities all over the country.

The *Spark Program* was launched in 1986, aiming to revitalize the rural economy through science and technology. Its primary objective was to help transfer and diffuse technology and knowledge to rural areas, stimulate the development of local agricultural and other industries, and improve the overall quality of life of farmers and rural households. Key initiatives include guiding farmers to change their traditional production methods and lifestyles and training personnel on rural applicable technology and management. For instance, according to a study from the Innovation Policy Platform (2016), in 2012 the Spark Program launched 1,473 projects, with a total of RMB 200 million in funding to implement 5,062 various types of training bases and 3,180 schools. Furthermore, Spark technology training invested RMB 4,279 billion at all levels, training 11.83 million people, compiling 21,800 kinds of teaching materials, printing 11.43 million publications, and writing 16,000 distance-learning texts, and in 2013, the Spark Program supported 3,454 brand-name projects at all levels.

In order to support the analysis of China's central government efforts towards innovation, this study presents some KPIs as evidence of the country's priorities and achievements with R&D initiatives. To begin with, statistics shows that expenditure on education has been a clear priority, for instance, in 2007 it represented 2.6% of the GDP, but in 2019 it grew to 3.5% of the GDP. Furthermore, in terms of absolute values, the increase on education annual expenditure by the central government was five-fold when comparing 2019 versus 2007, as shown on the Exhibit 08.

Exhibit 08 – China's National Government Expenditure (billion yuan)

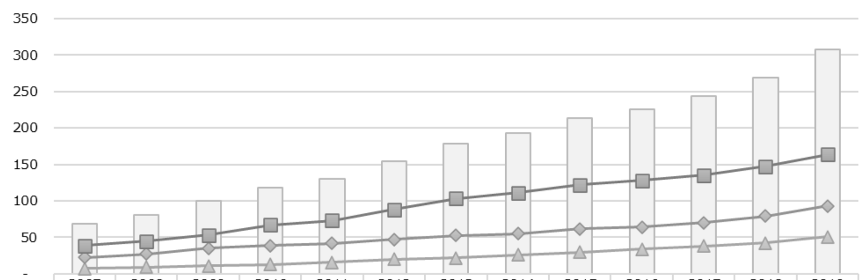


	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total Expenditure	4 978	6 259	7 630	8 987	10 925	12 595	14 021	15 179	17 588	18 776	20 309	22 090	23 886
General Public Services	851	980	916	934	1 099	1 270	1 376	1 327	1 355	1 479	1 651	1 837	2 034
Education	712	901	1 044	1 255	1 650	2 124	2 200	2 304	2 627	2 807	3 015	3 217	3 480
Science and Technology	214	261	328	420	383	445	508	531	586	656	727	833	947

Source: *data extracted on 08 July 2021 from National Bureau of Statistics of China.*

Looking at the government's expenditure on R&D specifically, it has also increased at a similar pace, but with higher intensity on basic research, which increased almost seven-fold in annual expenditure comparing 2019 versus 2007 (see details on Exhibit 09). As a result, the share of basic research expenditure on the total R&D expenditure increased from 11% in 2007 to 17% in 2019.

Exhibit 09 – National Expenditure on R&D of Scientific R&D Institutions (billion yuan)

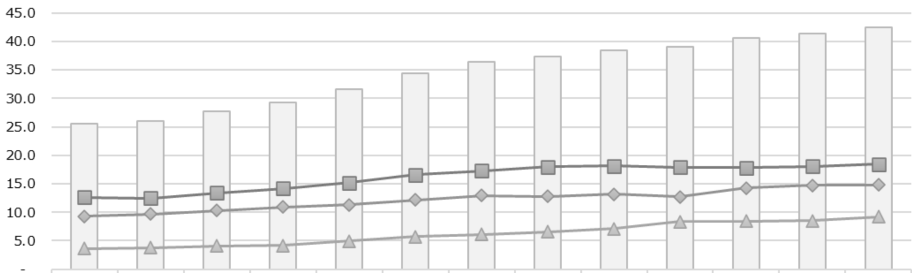


	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total Expenditure	69	81	100	119	131	155	178	193	214	226	244	269	308
Expenditure on Basic Research	7	9	11	13	16	20	22	26	30	34	38	42	51
Expenditure on Applied Research	23	27	35	39	42	47	53	55	62	64	70	79	93
Expenditure on Experimental Development	39	45	53	67	73	88	103	111	122	128	135	148	164

Source: *data extracted on 08 July 2021 from National Bureau of Statistics of China.*

This trend can be seen as a clear indicative of China's prioritization toward innovation, for instance, scholars and practitioners commonly defend that basic research is key to expand a country's knowledge base, thus laying ground for major discoveries and leading to innovation. Furthermore, the share of full-time equivalent (FTE) of R&D personnel dedicated to basic research has also grown more intensely if compared to other fields, as shown on the Exhibit 10.

Exhibit 10 – Full-time Equivalent of R&D Personnel of Scientific R&D Institutions (10000 man-year)



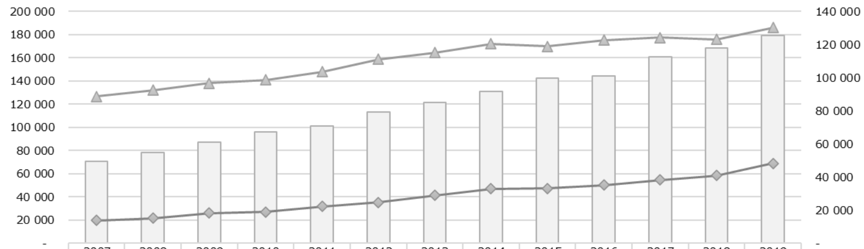
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total FTE	25.5	26.0	27.7	29.3	31.6	34.4	36.4	37.4	38.4	39.0	40.6	41.3	42.5
FTE for Basic Research	3.6	3.8	4.1	4.2	5.0	5.7	6.1	6.6	7.1	8.4	8.4	8.5	9.2
FTE for Applied Research	9.3	9.7	10.3	10.9	11.3	12.1	13.0	12.8	13.1	12.7	14.3	14.8	14.8
FTE for Experimental Development	12.6	12.5	13.4	14.2	15.2	16.6	17.3	18.0	18.1	17.9	17.8	18.1	18.4

Source: *data extracted on 08 July 2021 from National Bureau of Statistics of China.*

Not by coincidence, the investments and efforts on R&D institutions have brough positive results to China (see Exhibit 11). Furthermore, according to China's Policy Watch (2021) some policies for S&T development were key to support this trend, namely:

- Equity incentives and income distribution to motivate scientific and technical personnel.
- Incentives for scientific achievements to be sold to small and medium-sized enterprises.
- Increase of commercialization rewards, ensuring at least 50% to major researchers.

Exhibit 11 – Outputs of Scientific R&D Institutions

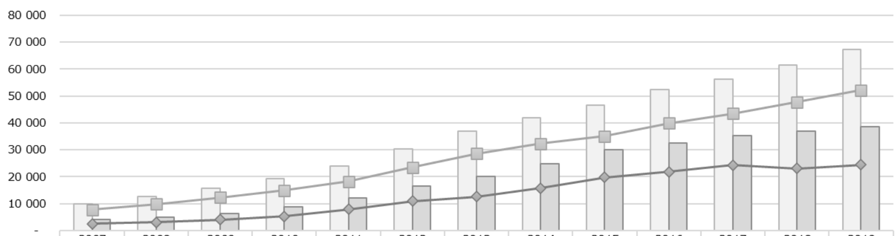


	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
R&D Projects (unit)	49 453	54 900	61 135	67 050	70 967	79 343	85 069	91 465	99 559	100 925	112 472	117 871	125 642
Scientific Papers Issued (unit)	126 527	132 072	138 119	140 818	148 039	158 647	164 440	171 928	169 989	175 169	177 572	176 003	185 978
Scientific Papers Published in Foreign Periodicals (unit)	19 596	21 498	25 882	26 862	31 598	35 173	41 072	47 032	47 301	50 010	54 500	58 440	68 776

Source: *data extracted on 08 July 2021 from National Bureau of Statistics of China.*

In terms of patents, the evolution was even more remarkable, in which the number of annual patents applications increased almost seven-fold (2019 versus 2007), while annual patents granted increased almost ten-fold at the same period, as shown on Exhibit 12.

Exhibit 12 – Patents of Scientific R&D Institutions

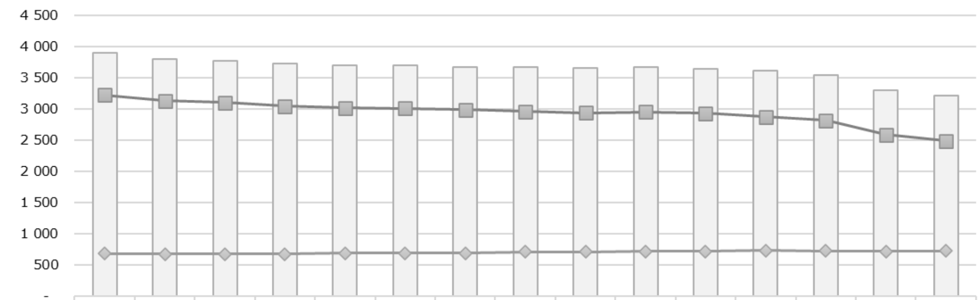


	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Patents Applications Accepted (item)	9 802	12 536	15 773	19 192	24 059	30 418	37 040	41 966	46 559	52 331	56 267	61 404	67 302
Patents Applications Granted (item)	4 036	5 048	6 391	8 698	12 126	16 551	20 095	24 870	30 104	32 442	35 350	36 778	38 476
Inventions Patents Applications Accepted (item)	7 782	9 864	12 361	14 979	18 227	23 406	28 628	32 265	35 092	39 854	43 426	47 740	52 185
Inventions Patents Applications Accepted (item)	2 467	3 102	4 077	5 249	7 862	10 935	12 542	15 786	19 720	21 816	24 283	23 098	24 486

Source: *data extracted on 08 July 2021 from National Bureau of Statistics of China.*

Finally, another relevant finding is that the number of Scientific R&D institutions has decreased between the period from 2007 to 2019 (see details on Exhibit 13). China's government has been able to foster higher productivity by launching policies to benefit specific fields such as focusing investments in new technologies and increasing the rigor of evaluation of research centers, thus pushing Scientific R&D institutions to scale up and increase productivity.

Exhibit 13 – Number of Scientific R&D Institutions (units)



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total R&D Institutions	3 901	3 803	3 775	3 727	3 707	3 696	3 673	3 674	3 651	3 677	3 650	3 611	3 547	3 306	3 217
Subordinated to Central Level	679	673	674	678	691	686	686	710	711	720	715	734	728	717	726
Subordinated to Local Level	3 222	3 130	3 101	3 049	3 016	3 010	2 987	2 964	2 940	2 957	2 935	2 877	2 819	2 589	2 491

Source: *data extracted on 08 July 2021 from National Bureau of Statistics of China.*

To conclude, the events, policies, and data presented so far are compelling evidence that the role of China's central government has been key in paving the way towards technology/scientific development and innovation. In the next sections this study will explore how the other two major players of the Triple Helix (namely, the Academia and Industry) have also played key roles to develop China's national innovation ecosystem.

4.3.2. National Academia

China has the largest education system in the world, for instance, according to the portal China Education Centre (2021), in July 2020 there were 10.7 million students taking the National Higher Education Entrance Examination (Gao Kao). In 2019, there were all together 2688 Higher Education Institutions (HEIs), among which 1265 were universities, 257 were independent colleges, and 1423 were higher vocational colleges. There were also 268 higher education institutions for adults. Furthermore, the total enrolment of students achieved the following numbers in 2019:

- Undergraduate in the regular HEIs: above 30.3 million.
- Postgraduate in the regular HEIs: above 2.8 million.
- Adults in HEIs: above 6.6 million.
- International students in HEIs: above 490 thousand.

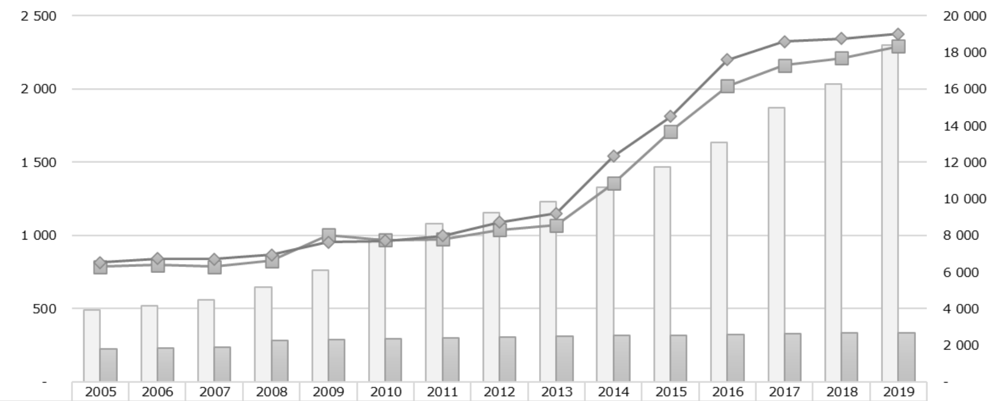
In recently years, the Chinese HEIs emphasized the practical research and development to cope with the economic construction of the country and made great effort to serve the central task of strengthening the basic research. In addition, HEIs have taken part in the construction of science parks, establish high-tech enterprises run by HEIs, and combine industry, teaching, and research to turn the scientific and research fruits into real productivity and spread them to the whole society.

Since the reform and opening to the outside world in 1978, international cooperation and exchanges of higher education have become more active in China. For instance, through the reform of sending and management of overseas students, the Chinese government adopted the policy of supporting overseas studies, encouraging overseas students to come back after they complete their studies. Historically, the *Project 211* and the *Project 985* represent the major initiatives that China have been key to develop its higher education landscape.

Project 211 aimed at strengthening about 100 institutions of higher education and key disciplinary areas as a national priority for the 21st century. Primarily aiming at accelerating the national economic progress by pushing forward the development of science, technology, and culture, enhancing China's overall capacity and international competitiveness, and laying the foundation of training high-level professional manpower mainly within the educational institutions at home.

Furthermore, this group of institutions contributed with the establishment of national standards in overall quality, close or equivalent to those of advanced international standards. Hence, most of the HEIs have enhanced their physical conditions and staff competence, their human resources training and scientific research, and have adapted to regional and sectorial development needs. Nowadays, the HEIs which are part of the Project 211 list take on the responsibility of training approximately 20% of doctoral students, 65% of graduate students, 50% of foreign students and 30% of undergraduates. They offer 85% of the State's key subjects; hold 96% of the State's key laboratories; and utilize 70% of scientific research funding. A compelling evidence universities' increasing focus on innovation can be found on the statistics of R&D institutions within HEIs, which increased almost five-fold in 15 years (see Exhibit 14).

Exhibit 14 – China's Number of Higher Education Institutions (HEIs)



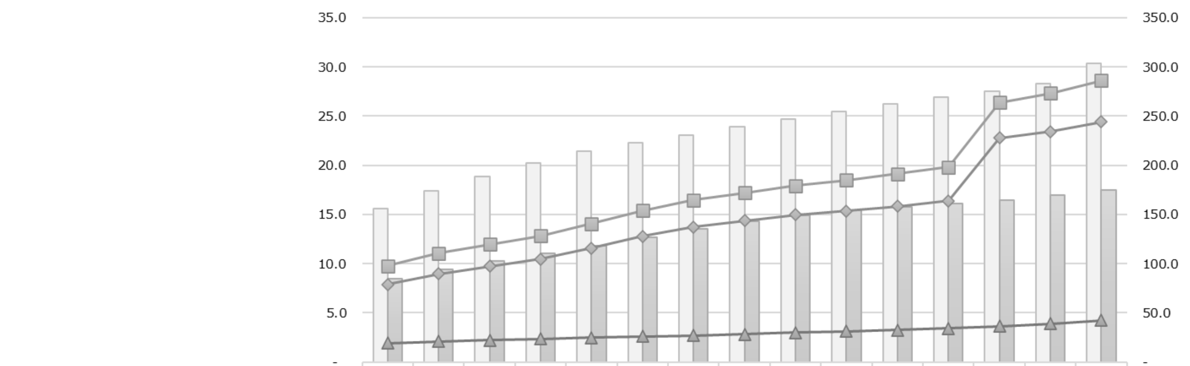
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
R&D HE Institutions	3 936	4 154	4 502	5 159	6 082	7 833	8 630	9 225	9 842	10 632	11 732	13 062	14 971	16 280	18 379
General HE Institutions	1 792	1 867	1 908	2 263	2 305	2 358	2 409	2 442	2 491	2 529	2 560	2 596	2 631	2 663	2 688
Natural Sciences & Technology	786	800	786	827	1 003	970	975	1 039	1 070	1 356	1 713	2 021	2 162	2 211	2 294
Social Sciences & Humanities	815	843	840	869	954	963	997	1 090	1 150	1 540	1 814	2 199	2 325	2 346	2 376

Source: *data extracted on 10 July 2021 from National Bureau of Statistics of China.*

Project 985 was launched in 1998 to push key Chinese HEIs to achieve first-rate rankings and prestigious reputation of international advanced levels. The project started with 9 universities and reached 39 universities in 2004, involving both national and local governments by allocating large amounts of funding to certain universities to build new research centres, to improve and modernize facilities, hold international conferences, attract world-renowned faculty and visiting scholars, and helping Chinese faculty attending conferences abroad.

Furthermore, the enrolment of students on advanced levels such as Postgraduation and Master's Degree courses also increase sharply especially from 2017 as detailed on the Exhibit 15 This can be considered beneficial for future development since advanced degrees are the foundation for fostering enrolment on Doctor's Degree courses, thus representing a potential contingent of new scientists and researchers in the near future.

Exhibit 15 – Number of Total Enrolment of Students (100,000 persons)

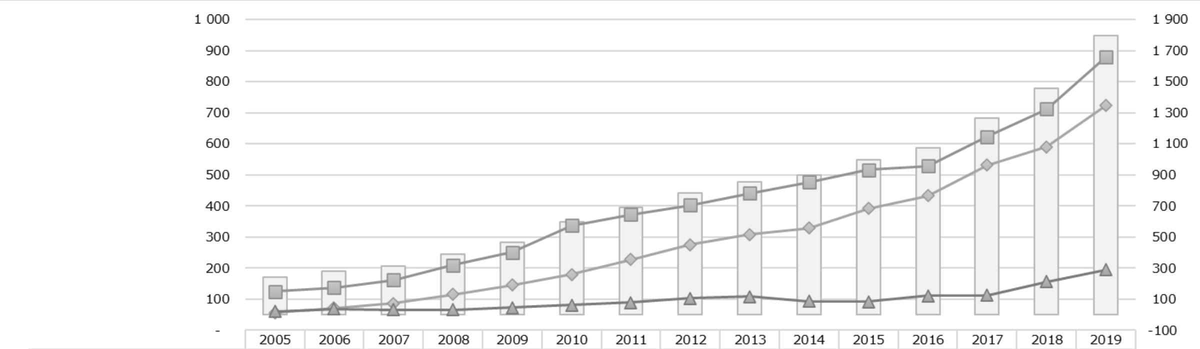


	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Regular Undergraduates and College Students	156.2	173.9	188.5	202.1	214.5	223.2	230.9	239.1	246.8	254.8	262.5	269.6	275.4	283.1	303.2
Regular Full Undergraduate Courses	84.9	94.3	102.4	110.4	118.0	126.6	135.0	142.7	149.4	154.1	157.7	161.3	164.9	169.7	175.1
Postgraduates	9.8	11.0	12.0	12.8	14.0	15.4	16.5	17.2	17.9	18.5	19.1	19.8	26.4	27.3	28.6
Master's Degree	7.9	9.0	9.7	10.5	11.6	12.8	13.7	14.4	15.0	15.4	15.8	16.4	22.8	23.4	24.4
Doctor's Degree	1.9	2.1	2.2	2.4	2.5	2.6	2.7	2.8	3.0	3.1	3.3	3.4	3.6	3.9	4.2

Source: *data extracted on 10 July 2021 from National Bureau of Statistics of China.*

In terms of investments on the different levels of research, similarly to the trends previously presented regarding R&D institutions under the government control, it is possible to also identify a strong focus on basic research from the R&D institutions under the higher education control. For instance, the overall expenditure on basic research has grown around twelve-fold at the same period (see Exhibit 16).

Exhibit 16 – Expenditure on R&D of Higher Education (100 million yuan)

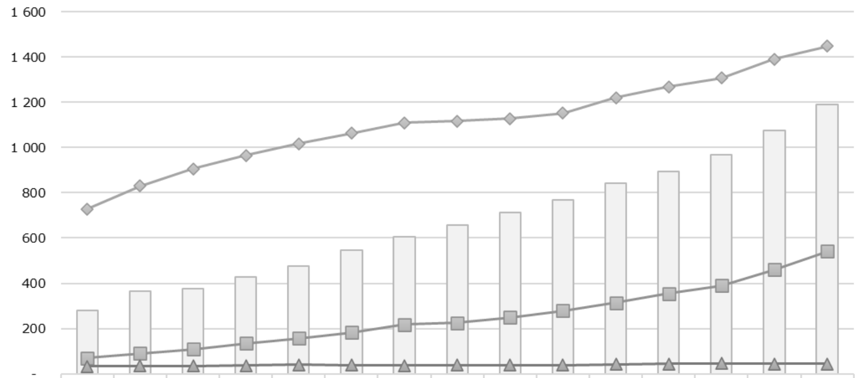


	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total Expenditure	242	277	315	390	468	597	689	781	857	898	999	1 072	1 266	1 458	1 797
Basic Research	57	71	87	115	146	180	227	276	308	329	391	432	531	590	722
Applied Research	125	137	162	209	250	337	372	403	441	476	516	528	623	712	879
Experimental Development	61	68	66	67	73	80	90	102	108	93	91	111	112	157	195

Source: *data extracted on 10 July 2021 from National Bureau of Statistics of China.*

Finally, the HEIs have been able to improve their output, such as the number of R&D projects, scientific papers issued (especially in foreign periodicals), and patents (especially the rate of patents granted), as detailed on the Exhibits 17 and 18 respectively.

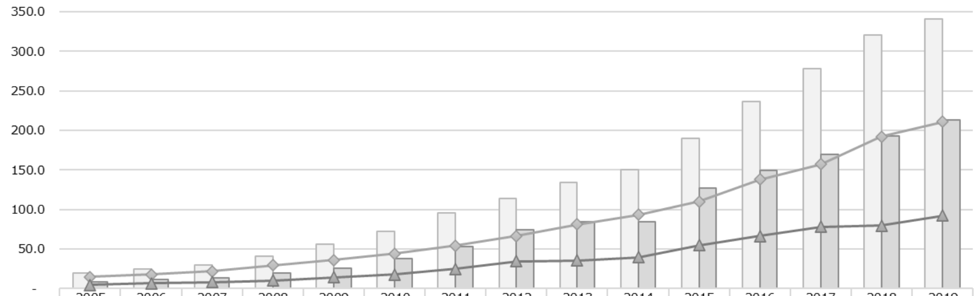
Exhibit 17 – Outputs of Higher Education Institutions (thousand units/items)



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
R&D Projects	280	365	375	429	477	548	604	657	711	767	842	894	967	1 077	1 189
Scientific Papers Issued	728	831	906	965	1 016	1 063	1 110	1 118	1 127	1 152	1 220	1 268	1 308	1 390	1 447
Scientific Papers Published in Foreign Periodicals	70	91	109	134	157	182	218	226	250	279	314	355	390	459	543
Publication on Science & Technology	33	35	36	38	41	38	37	39	38	39	43	45	46	45	43

Source: *data extracted on 10 July 2021 from National Bureau of Statistics of China.*

Exhibit 18 – Patents of Higher Education Institutions (thousand units/items)



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Patents Applications	20.1	24.5	29.9	40.6	56.6	72.7	95.6	113.4	133.9	150.0	190.4	236.7	277.5	320.8	340.7
Patents Granted	8.8	12.0	14.1	19.2	25.6	37.5	53.1	74.6	84.9	85.0	127.3	149.5	169.7	193.0	213.2
Inventions Patents Applications	14.7	18.1	21.9	29.3	36.2	44.1	54.4	66.8	81.3	93.4	109.9	137.8	157.1	192.0	210.9
Inventions Patents Grantedted	4.7	6.7	8.3	10.2	14.4	18.1	25.1	34.4	35.9	39.5	55.0	66.4	78.3	79.8	92.4

Source: *data extracted on 10 July 2021 from National Bureau of Statistics of China.*

4.3.3. National Industry

China’s industry is currently regulated by the *Ministry of Industry and Information Technology of the People’s Republic of China (MIIT)* which was established in 2008 as a department under the State Council responsible for the administration of China’s industrial branches and information industry. According to the official website from MIIT (2014), the institution goals are:

- To determine China’s industrial planning, policies, and standards.
- To monitor the daily operation of industrial branches.
- To promote the development of major technological equipment and innovation concerning the communication sector.
- To guide the construction of information system.
- To safeguard China’s information security.

The goals from the MIIT clearly emphasize the current focus on the industry modernization and informatization, especially because China's high growth on the past 50 years based on resource-intensive manufacturing, exports, and low-paid labour has reached its limits and has led to economic, social, and environmental imbalances (World Bank China, 2021).

Hence, this section aims to present the main recent programs put in place to foster industrial development, modernization, and innovation in China. The forementioned will be supported by statistical data to bring light to the main industrial inputs and outputs in this matter.

To begin with, on top of the main S&T programs previously mentioned on the section about the national government, China has launched several other initiatives that clearly place innovation as a priority under the current administration. The government wants to change the perception of China as a low-end manufacturer to a high-end producer while also reducing the country's dependence on foreign technology. For instance, since 2001 China has been part of the World Trade Organization (WTO[5]) and, to cope with the new challenges and demands after this association, the *Ministry of Science and Technology* decided to organize and implement 12 mega-projects of science research based on the 863 Program and the National Key Technologies R&D Program. The goal is to develop new products and nurture new industries, covering mechanisms related to human resource strategy, patent strategy, and standards strategy, allocating a total investment of approximately RMB 20 billion (USD 2.4 billion).

In 2015, China's government has announced the *Internet Plus Program*, aiming to integrate mobile internet, cloud computing, big data, and the Internet of Things with modern manufacturing, to encourage healthy development of e-commerce, industrial networks, and Internet banking, and to guide Internet-based companies to increase their presence in the international market (The State Council, 2015). The program encompasses initiatives such as increasing of funds for R&D, decreased dependency on non-domestic technology innovation, access to 100 MB/s internet connections for people in large cities, broadband connectivity to reach 98 percent of population, more funds for promoting business development and innovation. The goal is that by 2025, Internet Plus will become a new economic model and an important driving force for economic and social innovation and development.

In terms of general policies for entrepreneurship facilitation and innovation acceleration within the industry, it is possible to identify some key measures from China's government website Policy Watch (2021), such as implementation of preferential policies for knowledge-intensive start-ups, linkage between scientists and enterprises to foster diverse funding outside government budgets and market creation for new technologies, reduction of preapproval items for business registration, establishment of more favourable tax policies, new regulations for better protection of IPR, among others. For more details, see Exhibit 19 which provides a summary of the most relevant policies.

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[5] The World Trade Organization (WTO) is the only global international organization dealing with the rules of trade between nations. At its heart are the WTO agreements, negotiated and signed by the bulk of the world's trading nations and ratified in their parliaments. The goal is to ensure that trade flows as smoothly, predictably and freely as possible between its 164 member countries.

Exhibit 19 – China's key measures for Entrepreneurship and Innovation Facilitation

Focus Areas	Measures taken
Entrepreneurship Facilitation	• Cancelation of more than 150 approval items on taxation and departmental preapproval on local enterprises' issuing bonds. • Expansion of the coverage of *three-in-one business license* (allowing new companies to apply for a single integrated business license instead of three separate certificates). • Implementation of preferential policies for knowledge-intensive start-ups. • Improvement of the business incubator system, adding innovation services and maker spaces, and establishing standards for open technology markets. • Linkage between scientists and enterprises to foster diverse funding outside government budgets and market creation for new technologies. • Reduction of preapproval items for business registration. • Regulations update to create an equal opportunity business environment and improve market exit mechanism. • Facilitation of technology trade and promotion of international exchanges and cooperation.
Innovation Acceleration	• Financial and technical support to small and medium-sized enterprises involved in high-tech research and development of products. • Improvement of the proportion of earnings for researchers and their teams aiming to encourage innovation by rewarding innovators. • Permanent resident permits for high-level overseas talent and subsidies to high-tech professionals. • Expansion of regional hubs to promote innovation. • Facilitation of high-skilled foreigners to enter and stay at the country (focused on the main innovative cities). • Implementation of new national development zones and demonstration zones to foster massive innovation, attract foreign investment, and learn about advanced technologies. • Increase of subsidies granted for facilities such as offices, water, power, and internet. • Minimization of governmental intervention and reform of management systems to encourage innovation. • Opening for leading enterprises to join state-level research projects. • Permission for factories and warehouses unused to be converted into innovation bases and makerspaces. • Relaxation of regulations covering the transfer of scientific and technological research achievements from national research institutions to enterprises. • Removal of more than 10 departmental administrative license constraining mass entrepreneurship and innovation. • Integration of military technologies for civilian purposes, developing high-tech through military-civil integration and knowledge transfer. • Enhancement of security and track of classified data, such as national defense, trade secrets and personal privacy, to avoid leaks and erase lost data. • Establishment of more favorable tax policies, mainly in the form of tax-deductible over R&D costs. • Incentives for financial institutions to improve the percentage of medium-and long-term loans to the manufacturing sector to support innovations. • New regulations for better protection of IPR. • Rise of investment fund up to 120 billion yuan ($19 billion) to support the development of microchips.

Source: *China Policy Watch 2021.*

Finally, one of the most ambitious and important programs launched recently is the *Made in China 2025*, announced also in 2015 as a national strategic plan to further develop the manufacturing sector aiming to secure China's position as a global powerhouse in high-tech industries. For instance, leading economies with high-tech industries such as Germany and the United States have expressed their hostility to the initiative since it would move China from a low-cost manufacturer to a direct added-value competitor. Nonetheless, the program aims to use government subsidies, mobilize state-owned enterprises, and pursue intellectual property acquisition to surpass western industries as summarized on Exhibit 20.

Exhibit 20 – Program *Made in China 2025* key measures

Focus Areas	**Measures Taken**
Forced technology transfers in exchange for market access	Increased requirements for foreign companies to share advanced technologies in order to have access to the Chinese market.
Procurement restrictions for foreign invested enterprises	China's public procurement market remains largely closed to foreign suppliers (it favours domestic producers, especially in the information technology sector).
Standards	Chinese government ministries and companies have moved aggressively to participate in the development of international standards to ensure that Chinese-developed technology is included in them (such as 5G technology).
Subsidies	Central and local governments provide direct and/or indirect support to favoured companies in priority industries, such as loans from state owned banks on non-commercial terms.
Financial Policy	The government calls for the financial industry to provide full-scale support by introducing financial regulations to contribute to building up China as a manufacturing power.
Government-backed investment funds	Beyond the provision of subsidies, the central and local governments have established a large number of investment funds to support priorities outlined in the program.
Support from local government	Local governments also provide subsidies to develop their own *local champions*, by using government procurement strategically and establishing their own investment funds.
Technology-seeking investments abroad	Since 2015, an unprecedented wave of outbound investments into firms in Europe and elsewhere in industries of relevance to China have been successfully completed. However, many of these investments have been in areas where European enterprises are unable to make equivalent investments in China.
Stated-Owned Enterprises (SOEs)	Since 2015, big SOEs have emerged due to merges and acquisitions in industries such as nuclear, rail, shipping, materials and grains. The State Council aims to regroup a number of parent SOEs into pro-innovation and internationally competitive national enterprises.
Public-private partnerships	Public-private partnerships (PPPs) have been put forward as an important channel for attracting private investment into a wide range of projects initiated by government in areas like infrastructure and public services.

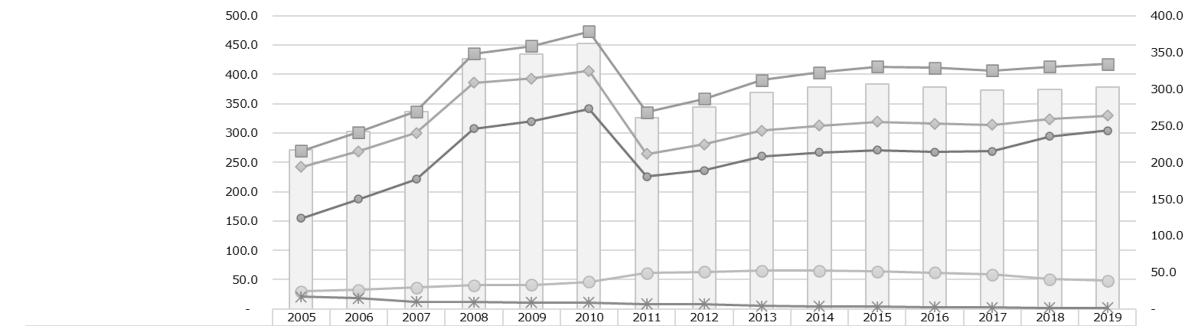
Source: *European Union Chamber of Commerce in China, 2017.*

In terms of innovative activities more specifically, it is remarkable to observe that in 2017, China's R&D spending was about $280 billion (representing 20% of total world R&D expenditure), with the rate of R&D investment exceeding the US and the EU. Furthermore, over the past 15 years, China has tripled its high-impact scientific efforts reaching the share of top 10% most-cited publications (European Commission, 2018). To further understand the phenomenon of industrial development in China, this research will explore some statistical data.

To begin with, it is important to visualize how the main indicators around Chinese industrial enterprises have evolved. To illustrate it, this study uses data from the so-called *industrial enterprises above designated size*, which are all state-owned enterprises and non-state-owned enterprises with annual revenue from principal business over 5 million yuan (National Bureau of Statistics of China, 2021). Also, the aggregation of all *sub-dimensions (sub-categories)* presented do not necessarily sum-up the totals because this study does not show all the classifications adopted by the National Bureau of Statistics of China to avoid additional complexity in reading the results.

For instance, Exhibit 21 shows that the number of industrial enterprises increased 39% from 2005 to 2019 with a strong focus on the private enterprises which increased 97% at the same period (while the stated-owned enterprises decreased -91%). This finding corroborates that China has successfully pushed the private sector to increase relevance on the country's economy.

Exhibit 21 – China's Number of Industrial Enterprises (thousand units)

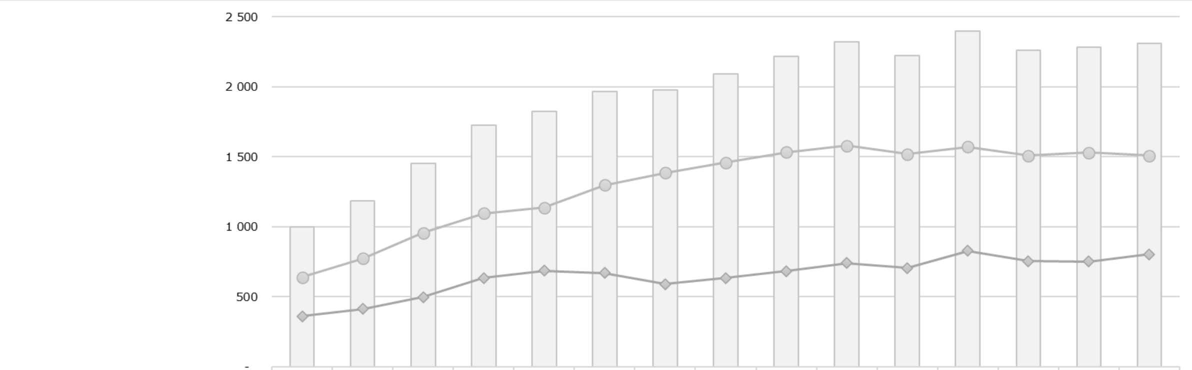


	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total	271.8	302.0	336.8	426.1	434.4	452.9	325.6	343.8	369.8	377.9	383.1	378.6	372.7	375.0	377.8
Large and Medium-sized Enterprises	29.8	32.9	36.5	40.4	41.3	46.6	61.3	63.3	65.5	65.3	63.7	62.3	58.9	51.1	48.2
Small Enterprises	242.1	269.0	300.3	385.7	393.1	406.2	264.3	280.5	304.3	312.6	319.4	316.3	313.9	323.9	329.6
Domestic Funded Enterprises	215.4	241.1	269.3	348.3	359.0	378.8	268.4	286.9	312.4	322.7	330.4	329.0	325.3	330.3	334.2
State-owned Enterprises	16.8	14.6	10.1	9.7	9.1	8.7	6.7	6.8	4.0	3.5	3.2	2.5	1.9	1.5	1.5
Private Enterprises	123.8	149.7	177.1	245.9	256.0	273.3	180.6	189.3	208.4	213.8	216.5	214.3	215.1	235.4	243.6

Source: *data extracted on 12 July 2021 from National Bureau of Statistics of China.*

In terms of foreign capital of industrial enterprises, the overall growth has been impressive, with a 131% increase from 2005 to 2019 as shown on Exhibit 22.

Exhibit 22 – Foreign Capital of Industrial Enterprises (billion yuan)



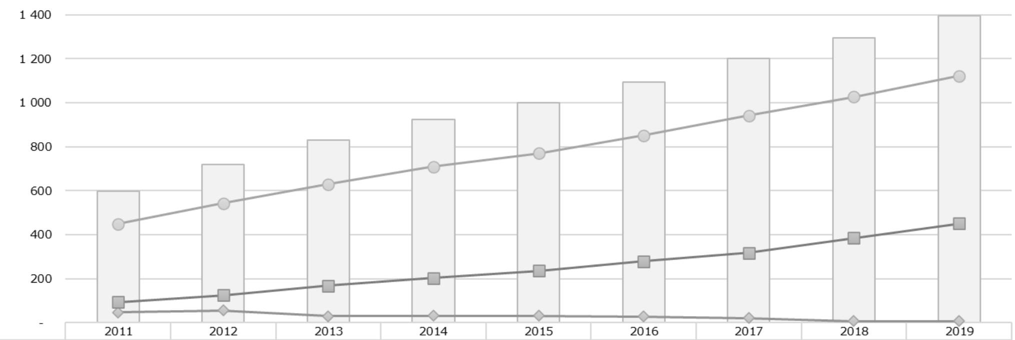
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total	999	1 186	1 452	1 728	1 823	1 966	1 976	2 093	2 215	2 322	2 223	2 398	2 262	2 282	2 313
Large and Medium-sized Enterprises	639	774	955	1 095	1 138	1 297	1 386	1 459	1 532	1 580	1 518	1 571	1 509	1 530	1 509
Small Enterprises	361	412	496	633	685	669	589	634	683	741	705	827	753	752	804

Source: *data extracted on 12 July 2021 from National Bureau of Statistics of China.*

Moving forward, this study will focus on the KPIs related to basic industrial R&D inputs and outputs, however, the statistics available are incomplete before the year of 2011, for this reason the study will be limited to this time frame onwards to ensure comparability between the analysis.

Exhibit 23 shows that while the total annual R&D expenditure has increased 2.3 times from 2011 to 2019, the private industrial enterprises expenditure increased almost five-fold at the same period. Thus, once again corroborating the increasing relevance of this sub-sector for China’s innovative development.

Exhibit 23 – Expenditure on R&D of Industrial Enterprises (billion yuan)



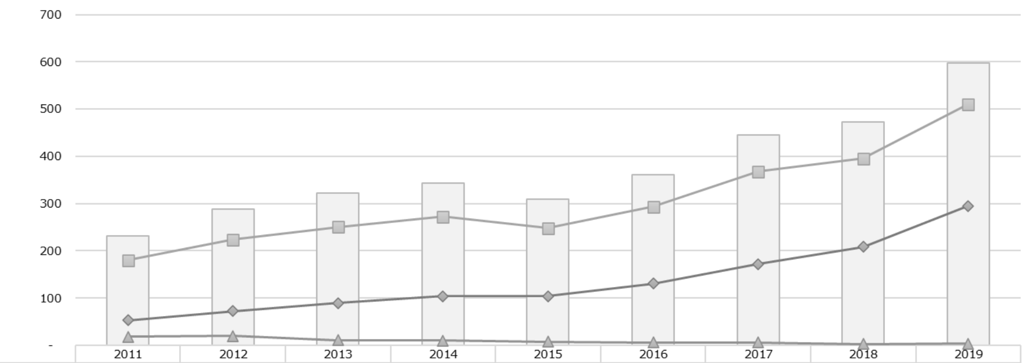
	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total	599	720	832	925	1 001	1 094	1 201	1 295	1 397
Domestic Funded Enterprises	450	544	630	710	771	853	942	1 027	1 122
State-owned Enterprises	47	56	31	33	32	28	21	8	8
Private Enterprises	94	125	169	203	236	280	319	385	452

Source: *data extracted on 12 July 2021 from National Bureau of Statistics of China.*
Note: *domestic funded enterprises refer to business without participation of foreign direct investment.*

As expected, the R&D outputs were positive. First, the number of projects conducted by those enterprises has increased at a similar pace of R&D expenditure. For instance, Exhibit 24 shows that the total number of projects has increased 2.5 times from 2011 to 2019, while the number of projects conducted by private enterprises increased 5.6 times at the same period. Second, the number of patents applications also followed a similar trend, with overall increase and stronger performance from the private enterprises (see details at Exhibit 25).

Additionally, according to info from the World Intellectual Property Organization (WIPO, 2021), China has also improved the level of international patents application, increasing around 4 times from 2011 (20,339 applications) to 2019 (84,279 applications). However, the absolute numbers of international patents still far below the domestic ones, representing that China still behind in terms of global novelty, which as key factor to enable international patenting. Furthermore, the rate of China’s international patents granted was 46.2% (38,959 patents) in 2019. More specifically, it is important to also understand the development in terms of *patents in force*, which represent a more tangible asset (since patent application does not yet represent rights granted or commercialization).

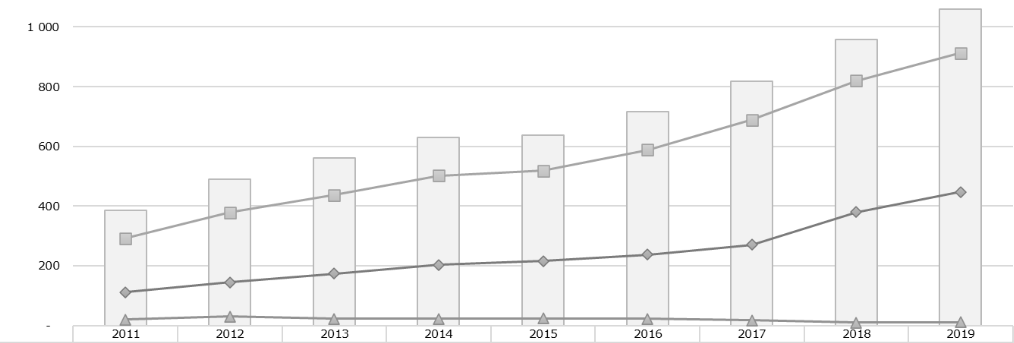
Exhibit 24 – Number of R&D Projects of Industrial Enterprises (thousand items)



	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total Projects	232	288	323	343	310	361	445	472	598
Domestic Funded Enterprises	180	223	251	272	248	293	368	395	511
State-owned Enterprises	18	20	11	10	8	6	6	3	4
Private Enterprises	53	72	90	104	104	130	172	209	295

Source: *data extracted on 12 July 2021 from National Bureau of Statistics of China.*
Note: *domestic funded enterprises refer to business without participation of foreign direct investment.*

Exhibit 25 – Number of Patents Applications of Industrial Enterprises (thousand items)



	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total Applications	386	490	561	631	639	715	817	957	1 060
Domestic Funded Enterprises	292	379	437	502	518	589	689	820	913
State-owned Enterprises	21	31	23	23	24	22	17	10	12
Private Enterprises	112	144	175	203	215	238	270	380	447

Source: *data extracted on 12 July 2021 from National Bureau of Statistics of China.*
Note: *domestic funded enterprises refer to business without participation of foreign direct investment.*

Furthermore, since this study has shown several times that China has been focusing on high-tech industry, we conclude this section by presenting data specifically from the high-tech sectors (see Exhibit 26) which presented the highest performance within the industrial enterprises. For instance, the top-five high-tech sectors which presented the highest growth in patents in force from 2011 to 2019 are Radar Equipment, Electronic Parts, Medical Treatment Equipment and Instruments, Biology and Biochemistry Products, and Electronic and Communication Equipment. In terms of total representativeness (share of patents in force), the sector of Electronic and Communication Equipment is the most important one with 70.3% of all patents in force in 2019 within China's high-tech industry.

Exhibit 26 – Number of Patents in Force in High-tech Industry (thousand units)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Growth % 2019 vs 2011
Total	82.2	115.8	138.8	180.6	241.4	316.7	379.6	425.1	471.9	574%

Top-Five High-Tech Sectors in Patent Growth (thousand units)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Growth % 2019 vs 2011
Radar Equipment	0.1	0.3	1.0	1.1	1.0	1.6	-	1.0	1.8	1488%
Electronic Parts	6.4	10.3	11.5	20.9	29.1	39.2	52.8	56.5	68.3	1060%
Medical Treatment Equipment and Instruments	2.4	3.3	4.1	5.3	8.0	10.9	12.2	16.9	17.4	723%
Biology and Biochemistry Products	1.1	1.6	2.4	3.5	4.2	5.7	6.3	6.9	7.6	660%
Electronic and Communication Equipment	51.2	71.6	88.6	119.1	167.8	224.9	267.0	295.2	331.8	648%

Source: *our analysis, based on data extracted on 12 July 2021 from National Bureau of Statistics of China.*

4.4. China's Sectoral Innovation System (SIS)

This section is focused on China's energy sector to explore how the country's Sectorial Innovation System (SIS) is organized. More specifically, China has achieved leadership in renewable energy, as indicated by its production figures. It is currently the world's largest producer of wind and solar energy, and the largest national and foreign investor in renewable energy.

In addition, four of the five largest renewable energy agreements in the world were made by Chinese companies in 2016. Regarding manufacturing, Chinese companies stand out, since five of the six largest solar module manufacturing companies in the world are Chinese, as well as the largest manufacturer of wind turbines in the world. More recently, according to data from the US Energy Information Administration (2021), in 2018 China achieved the global leadership in global energy production (117,798 quadrillion Btu), surpassing the previous leaders such as US (95,754 quadrillion Btu) and Russia (63,463 quadrillion Btu).

The effort of the Chinese government corresponds with the national policies of innovation and development, where the final objective is to develop an *ecological civilization*. This approach involves the different industries of the country to reduce the level of pollution and the use of fossil fuels, mitigate climate change and improve energy efficiency (CSIS, 2015).

The development of energy capacity from renewable sources has increased to 71.67 million kW in wind power and 48.2 million kW in solar power, according to data from the China National Energy Administration in 2020 (CEIC, 2020).

There is no doubt that the leadership achieved in recent years in renewable energy is the result of a joint effort between industry, academia, and government and that it directly affects the quality of life of Chinese citizens. This section explains the role of each of these three actors and the dynamics between them that make possible the synergy of the Chinese phenomenon in the renewable energy sector.

4.4.1. Green Energy Government and Policies

In recent years, energy demand has increased substantially in China, due to the growth of the industry and its population. Therefore, from a geopolitical perspective this means a growing dependence on fossil fuels (China's main energy source) that directly affect the energy security of the country. Furthermore, this also generates environmental deterioration, for this reason the government has defined three strategic priorities for sustainable development of energy, namely: (i) ensure long-term economic growth; (ii) reduce energy vulnerability; and (iii) protect the environment (He and Qin, 2006).

After the adoption of the Renewable Energy Law of the People's Republic of China in 2005, whose purpose was "promoting the development and utilization of renewable energy, increasing the supply of energy, improving the structure of energy, safeguarding the safety of energy, protecting environment and realizing a sustainable economic and social development" (Government of China, 2005), state efforts continued, with six specific objectives and measures applied to the achievement of each of them.

The six objectives are as follows: giving priority to thrift, relying on domestic resources, encouraging diverse patterns of development, relying on science and technology, protecting the environment and cooperation for mutual benefit. In turn, specific measures have been established in order to achieve the proposed goals. It is important to refer to them in more detail, as they are central to the success of China's energy strategy (Information Office of the State Council of the People's Republic of China, 2007).

Regarding the power supply capacity, the government has indicated vigorously develop renewable energy and improve energy development in rural areas. For instance, the "Lighting Project ", "campaigns for the renewal of the rural network," electrification of rural hydroelectric areas "and" connection of the villages with the network ", and full use of small hydroelectric plants, wind energy and solar energy for the power generation. Through these initiatives, the Chinese Government has solved the problem of 30 million people who did not have access to electricity, since they lived in remote areas not connected to the grid.

In terms of accelerating the progress of energy technologies, the focus is on making energy-saving technologies popular, stimulating innovation in key technologies, improving the level of equipment manufacturing, and developing scientific research. This is materialized in the National Plan for the Medium and Long Term of Scientific and Technological Development (2006 - 2010) launched in 2005. In this sense, the government seeks to gradually establish a market-oriented system, where companies play a leading role and combine efforts with universities and research institutes.

Policies aimed at promoting investment in renewable energy must also be considered, since they are a central element in achieving government objectives. Accordingly, China has implemented price and financial policies (that imply tax reduction) for those who invest in projects related to the development of renewable energy in the country. To illustrate the above, we will use the case of wind energy as an example. The China National Development and Reform Commission (NDRC) launched a *Wind Farm Concession Program* in 2003, according to this policy it is noted that investors and developers of wind energy projects (more than 50 MW) will be selected by bidding. In this way the development rate is increased, and the national manufacturing capacity is improved, thus reducing power generation costs and reducing electricity prices (Wang, 2010).

Sometimes managing the pricing and incentive policy is not an easy task. Policymakers face certain difficulties when designing the most appropriate one, since certain dilemmas arise. Zeng et al. (2013) argues that the price of renewable energy integration is difficult to establish, because the factors that affect it, such as technology and market scale, are limited. This implies that, on the one hand, a higher price will increase the burden on users, but in turn, the lower price will increase the provider's costs.

Another important element that explains the efficient and rapid deployment of renewable energy from the promulgation of the Law in 2005, is the financing strategy through a national surcharge on electricity consumption. In other words, the NDRC issued the *Provisional Measures on Renewable Energies Electricity Prices and Cost-sharing Management* in 2006, the NDRC basically ordered the pricing department to establish a energy surcharge applied to electricity users with a unified standard based on consumption. The effects of this price policy can be seen directly in the development of the industry and in the growth of investment in renewable energy. In the section dedicated to *Industry* we will refer to this in detail.

4.4.2. Green Energy Academia

A recent study by Ye et al. (2020) indicates that China currently has a remarkably efficient university knowledge transfer network. The dynamics of the network that, despite greater complexity, generates a greater transfer of knowledge and connectivity among its members. This is produced by the continuous incorporation of new universities, either from another region or from another country. In this way, new ties emerge in the network, acting as bridges of knowledge between the members who are in it. This is evidenced in the multiple alliances that China has developed with other countries, in its desire to promote international cooperation and the generation of knowledge. This complex network of connecting nodes, together with increasing patent activity (understand the number of citations and filling out the patent registration) of Chinese universities, act as knowledge transfer bridges, therefore, their role in the network it becomes crucial.

Next, we will refer to some of the most significant partnership that China has established with different countries in the renewable energy sector to illustrate the importance of the nodes network.

Australia and China are linked primarily to do research and share knowledge, through the alliance between the Australia-China Science and Research Fund (ACSRF) and the Joint Research Centres (JRC). The latter are virtual centres that link research institutions in Australia and China. Their joint activities are based on priority areas agreed between both governments.

The ACSRF-JRC activities include joint research programs with Chinese partners, conferences, workshops and symposia, exchange and secondment of personnel between Australia and China, new communication initiatives and exchange of information related to research (Australian Government, 2021).

A partnership with Denmark is essential if a country wants to have access to have those who have the greatest expertise in wind energy. The purpose of this agreement is to work together to move towards the energy transition, the Chinese government partnered with Denmark in 2010 to create The Sino - Danish Energy Centre (SDC). This centre has several participants from Academia such as Copenhagen Business School, University of China Academy of Sciences, Technical University of Denmark, Chinese Academy of Sciences, University of Copenhagen, Aarhus University and Aalborg University. The initiatives of both governments stand out in The *Wind Energy Program (WED)* implemented during 2007-2010, which aimed to develop capacities in wind energy to contribute to China's energy supply and *The Renewable Energy Program (RED)*, aimed at improving the development capacity of renewable energy in China (2009 - 2013) (SDC, 2020).

Germany is one of the greatest exponents in the development of solar energy and associated technologies, therefore also a strategic partner for China. The two governments came together to form the Sino-German Energy Association, which contributes to sharing the lessons learned from Germany's energy transition with China and raising awareness among Chinese energy sector stakeholders about the challenges involved in the energy transition. The priority areas of cooperation are the expansion (knowledge diffusion) of renewable energies and the increase of energy efficiency in industry and buildings. The energy association combines high-level government dialogue and expert advice, not only Chinese government entities such as the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) participate but also private entities such as BMWi (GIZ, 2021).

The United States is not only the second largest polluter in the world, but one of the largest economies that is also making great efforts generating energy from renewable sources. The country collaborates with China since global energy security and climate change are a priority for both. The North American country involves China in concrete collaborative projects that promote clean and efficient energy, energy sustainability, energy security, the reduction of carbon emissions and lower energy costs. About renewable energy, initiatives such as the Clean Energy Research Centre of the United States and China (CERC) and the Energy Efficiency Action Plan (EEAP) stand out. In this way, the US Department of Energy (DOE) uses this bilateral collaboration to lead the opening of markets and produce solutions to energy challenges (US Department of Energy, 2021).

The European Union also leads in terms of energy consumption, together with China they account for a third of world energy consumption. The partnership between the two giants focuses on energy cooperation to support the clean energy transition in both regions and thus provide clean, sustainable and affordable energy to their citizens. Common areas of work are energy efficiency, renewable energy sources, energy system design and transformation and global energy markets, and the role of innovative energy (European Union, 2021).

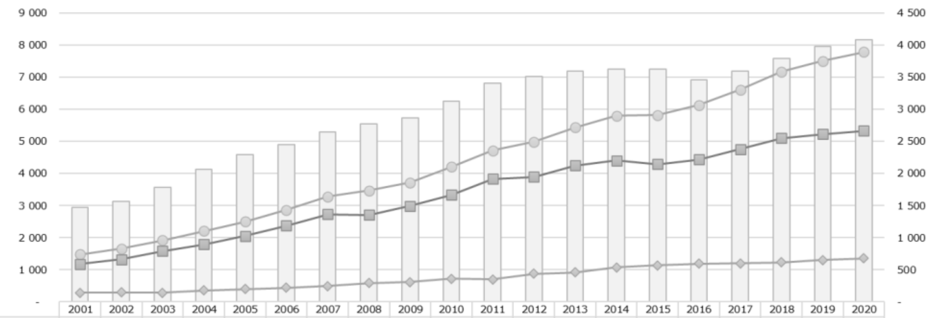
Finally, it is worth mentioning the global partnership China - United Nations International Development Organization (UNIDO). Specifically, through The International Solar Energy Centre for Technology Promotion and Transfer (ISEC), which was established in December 2005 jointly by the government of China and UNIDO. Currently the ISEC/Asia-Pacific Research and Training Centre for Solar Energy (APRTCSE) is the only centre focused on the research, promotion, and application of solar and other new and renewable energy technologies as well as technical cooperation and capacity building in China and abroad. According to UNIDO (2015), some of the outcomes of this partnerships are:

- More than 130 scientific research achievements have been gained, of which 26 items obtained awards on national and provincial levels.
- Over 290 technical papers have been published in domestic and international publications and international seminars.
- 70 domestic training workshops have been held by Gansu Natural Energy Research Institute (GNERI) and ISEC on solar water heater, solar cooker, solar building, solar photo-voltaic technique, energy saving and coal or firewood saving stove workshops.
- More than 700,000m2 solar houses were designed and developed.

4.4.3. Green Energy Industry

Before proceeding to the analysis of the renewable energy industry in China, it is necessary to indicate the context of the energy sector in general. First, the Exhibit 27 shows China's energy production from 2001 to 2020, this illustrates the growing energy demand of the country in the last two decades. Next, the Exhibit 28 shows a comparison between consumption and production in the same period (2001 - 2020), that is, it compares energy supply and demand. It is not difficult to realize the gap between the two, this has been one of the main reasons that has prompted the Chinese government to develop other sources of energy than coal or oil. This is what we mean when we point out that it is a *national security issue*.

Exhibit 27 – China's Total Primary Energy Production



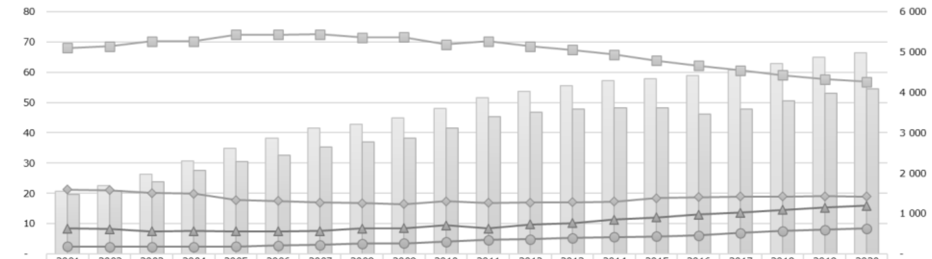
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total Primary Energy Production (million tons of SCE)	1 474	1 563	1 783	2 061	2 290	2 448	2 642	2 774	2 861	3 121
Power Generation (billion kwh)	1 481	1 654	1 911	2 203	2 500	2 866	3 282	3 467	3 715	4 207
Hydro Power Generation (billion kwh)	277	288	284	354	397	436	485	585	616	722
Thermal Power Generation(billion kwh)	1 177	1 327	1 580	1 796	2 047	2 370	2 723	2 707	2 983	3 332

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total Primary Energy Production (million tons of SCE)	3 402	3 510	3 588	3 622	3 622	3 460	3 589	3 789	3 973	4 080
Power Generation (billion kwh)	4 713	4 988	5 432	5 794	5 815	6 133	6 604	7 166	7 503	7 779
Hydro Power Generation (billion kwh)	699	872	920	1 073	1 130	1 184	1 198	1 232	1 304	1 355
Thermal Power Generation(billion kwh)	3 834	3 893	4 247	4 400	4 284	4 437	4 755	5 096	5 220	5 330

Source: *extracted on 14 July 2021 from National Bureau of Statistics of China.*

Note: *The coefficient for conversion of electric power into SCE (standard coal equivalent) is calculated on the basis of the data on average coal consumption in generating electric power in the same year.*

Exhibit 28 – China's Primary Energy Consumption



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total Energy Consumption (million tons of SCE)	1 555	1 696	1 971	2 303	2 614	2 865	3 114	3 206	3 361	3 606	3 870	4 021	4 169	4 283	4 341	4 415	4 558	4 719	4 875	4 980
Total Primary Energy Production (million tons of SCE)	1 474	1 563	1 783	2 061	2 290	2 448	2 642	2 774	2 861	3 121	3 402	3 510	3 588	3 622	3 622	3 460	3 589	3 789	3 973	4 080
Proportion of Coal (%)	68	69	70	70	72	72	73	72	72	69	70	69	67	66	64	62	61	59	58	57
Proportion of Petroleum (%)	21	21	20	20	18	18	17	17	16	17	17	17	17	17	18	19	19	19	19	19
Proportion of Natural Gas (%)	2	2	2	2	2	3	3	3	4	4	5	5	5	6	6	6	7	8	8	8
Proportion of Primary Electricity and Other Energy (%)	8	8	7	8	7	7	8	8	9	9	8	10	10	11	12	13	14	15	15	16

Source: *extracted on 14 July 2021 from National Bureau of Statistics of China*

According to recent data extracted from the US Energy Information Administration (2021) to counteract the growing energetic demand, China imports energy from other regions of the world and from several sources, including imports of fossil fuels such as coal, crude oil, and natural gas. In terms of crude oil, to guarantee an adequate supply of oil and mitigate geopolitical uncertainties, China has diversified import sources highlighting the contributions of Saudi Arabia 16%, Russia 15%, Iraq 10%, Angola 9%, Brazil 8%, and Oman 7%. Natural gas is another important source of energy, which China imports in two ways, liquefied and through pipelines. Liquefied Natural Gas (LNG) represents 62% of imports, Australia is the main supplier with a 29% share, while China receives 38% of natural gas through pipelines, with Turkmenistan being the largest supplier with a 25% share. Finally, coal, which is still the largest source of energy in the People's Republic of China in 2021, is imported from Indonesia (46% share) and Australia (26% share).

In summary, data shows that the energy sector has becomes a bottleneck for China's economic growth and the energy strategy must find a balance between consumption and demand to maintain stable economic growth (He and Qin, 2006). Thanks to the measures adopted by the People's Republic of China, the situation has evolved positively, as shown in Exhibit 29.

Exhibit 29 – China's energy production by type (quad Btu)

Year	Energy Source					Balance	
	Coal	Natural Gas	Petroleum and other liquids	Nuclear	Renewables and other	Total Production	Consumption
2000	30.83	1.01	6.99	0.16	2.28	41.26	42.42
2001	32.77	1.12	7.08	0.17	2.87	44.01	44.40
2002	34.53	1.21	7.27	0.25	2.94	46.20	47.66
2003	40.87	1.27	7.32	0.42	2.90	52.76	55.16
2004	47.27	1.50	7.50	0.48	3.57	60.33	66.61
2005	52.68	1.84	7.75	0.51	4.01	66.78	74.72
2006	57.23	2.16	7.88	0.52	4.39	72.19	82.60
2007	61.47	2.56	8.02	0.60	4.88	77.52	88.93
2008	64.66	2.81	8.16	0.66	6.07	82.35	93.00
2009	69.38	3.11	8.15	0.66	6.49	87.80	100.48
2010	76.36	3.48	8.76	0.72	7.72	97.03	112.33
2011	83.84	3.79	8.70	0.83	7.78	104.95	123.16
2012	87.86	3.83	8.77	0.94	9.59	110.99	131.81
2013	88.51	4.17	8.94	1.12	1.07	113.40	136.27
2014	87.63	4.56	9.04	1.26	1.23	114.79	137.91
2015	85.45	4.90	9.19	1.64	13.12	114.30	136.05
2016	77.14	5.01	8.58	2.02	14.30	107.05	132.02
2017	80.53	5.38	8.21	2.38	15.44	111.94	139.33
2018	84.25	5.87	8.10	2.79	16.79	117.80	147.57

Source: adapted from US Energy Information Administration, accessed on 12 July 2021.

The energetic matrix has diversified to other sources of energy different from oil and coal, such as wind, sun, biomass, natural gas, water and nuclear. In specific terms, the production of energy from renewable sources (wind, sun and water) has grown from 2,277 (quad Btu) in 2000 to 16,793 (quad Btu) in 2018. This increase is quite extraordinary, especially if we compare it with the growth of production and consumption during the same period. Production has ranged from 41,262 (quad Btu) to 117,798 (quad Btu), that is, it has multiplied by a factor of 2.85 app. Consumption has ranged from 42,417 (quad Btu) to 147.57 (quad Btu), which implies a growth factor of 3.48 app, while the production of renewable energy multiplied by a factor of 7.37 app. Government policies dedicated to promoting the energy transition towards renewable sources directly affect the stakeholders involved in the ecosystem, since within a system they must interact, cooperate and work towards common objectives in order to progress in the best way.

If we focus on the economic impacts generated by the development of renewable energy in China, we observe the following: it has a stronger promotional effect for the national economy compared to coal energy. According to Liu et al. (2019) this is due to its transfer effect, because the development of renewable energies plays a leadership role in other industries. This effect, at the same time, implies a higher demand for investment goods (with the expansion of the scale of renewable energy) which ultimately translates into an improvement of cross-sector linkages in the renewable energy sector. For example, the increasing demand for mechanical equipment such as wind turbines and silicon panels for photovoltaic and wind generation has stimulated the production of relevant renewable energy industries.

The development of renewable energy sources has faced a variety of obstacles, including the high cost of development, small market segment and weakness in the manufacturing industry. The government of the People's Republic of China has taken a series of measures to cope with them. Recently highlighted the Cooperation agreement on establishing the China Energy New Energy Industry Investment Fund (January 2021) with an initial amount of 10.02 billion yuan. The Fund focuses on investing in new technological projects of emerging industries such as wind power, photovoltaic power, hydrogen energy, energy storage, and integrated smart energy. After the Fund goes into operation, it is expected to stimulate about 50 billion yuan of funds to flow into the new energy industry and support the launch of wind and photovoltaic power projects with installed capacity exceeding 6 million kW. This is a government - industry agreement, China Energy (and his partners China Shenhua Energy Co., Ltd. and Guohua Energy Investment Co., Ltd) representing the government and China Guoxin Asset Management Co., Ltd. and China Orient Asset Management Co., Ltd. under China Reform Holdings Corporation Ltd. Guohua Investment and Development Asset Management Co., Ltd. representing private industry (CEIC, 2020).

In order to understand the role of the government in the renewable energy market we will refer to the case of the wind power market. In the wind energy market, the central government conducts and starts the process of stakeholder integration. It also establishes the renewable energy market through a series of policies and explicitly identifies buyers and promoters of the electricity market. Renewable energy buyers include grid companies, developers (various types of government - organized companies), and later the market share of utility companies and large-scale state power companies (Ming et al., 2014).

The growth of the renewable energy industry in the People's Republic of China observed over the last twenty years is definitely not the product of chance. We have exposed important insights that describe the dynamics of each of the actors (government - academia - industry) from an innovation system perspective, specifically using the triple helix model. The evidence supports, in general terms, the success of the system to generate an environment conducive to the generation, transfer and dissemination of knowledge. However, with respect to the detail of the analysis we will refer below using the framework proposed by Bergek et al. (2008) regarding technological innovation systems. According to this model, it is necessary to analyse the system using seven functions.

1) *Knowledge development and diffusion*: This function is evidenced by patent activity and investment in the renewable energy sector in the People's Republic of China. Regarding investment, China has been the largest investor in renewable energy over the last decade, investing $758 billion (Science Business, 2020). On the other hand, if we analyse patent activity, we observe that the growth of Chinese patent filings in green energy technologies has been extraordinary. Over the period 2005-15, Chinese origins increased from over 2,800 in 2005 to more than 45,700 in 2015, growing on average at 25.5% each year. With regards to patent families, China increased its number of families by 15.7% on average each year in 2005-15 (Rivera León et al., 2018). A recent study from WIPO (2020) also corroborates the position of China as leader at patent families in renewable energies, it states that in the period 2013 to 2017, for example, counting entire patent families, 45,472 patents originated from China, more than twice the number originating from Japan, which is ranked second (21,386). The trend is driven by solar technology, where Chinese applicants have three times the number of patents compared to those in Japan (WIPO, 2020).

2) Influence on the direction of search: This function is represented by the regulations, goals and targets imposed by the government regarding renewable energies. First, is necessary to mention that since 1990 international community has been exerting pressure on China to reduce GHG emissions. Moreover in 2007 when China became the world's largest CO2 emitter (The Guardian, 2007). As a response, Chinese government decided to act and initiates his energy transition process, therefore, from 2002 onwards, it launched a series of regulations aimed at developing the renewable energy sector. The Clean Production Promotion Law (2002) was the first one, followed by the National Plan for Medium and Long term Scientific and Technological Development (2006 – 2010) in 2005, the Renewable Energy Law (2006), the Medium and Long Term Development Plan for Renewable Energy (2007) and the 12th Five-Year Plan (2011-2015).

It is important to highlight the objectives of the Medium and Long Term Development Plan for Renewable Energy, because here are set the specific goals for China's renewable energy development in the coming 15 years such as to increase the proportion of renewable energy in total energy consumption, to resolve the problem of lack of electricity of people living in remote off-grid areas and the shortage of fuel for daily life needs in rural areas, to stimulate the utilization of organic wastes for energy, and to promote the development of renewable energy industries (Information Office of the State Council of the People's Republic of China, 2007).

3) Entrepreneurial experimentation: Regarding to this function is precise to consider the numbers of new entrants that come into the market of renewable energy. For instance, in the wind energy industry currently there are around 50 investors in developing wind farms plus 30 or so turbine manufacturers in operation by 2015 across China (CNREC, 2015, as cited in Shen, 2016), the top ten wind farm investors took up 72 per cent of total wind capacity development in 2014, and the top ten turbine manufacturers took over 80 per cent of the market share. From this perspective, the development of the wind energy industry is in the hands of fewer than 20 enterprises (Shen, 2016). It seems that the market is quite concentrated, however, the situation is better compared to in 2000 when the wind industry was ruled by just a few state-owned enterprises (SOEs). The Exhibit 30 shows that the situation has changed, for instance entrepreneurship has been encouraged and private capitals dominate the solar thermal, wind power, and solar module industries.

Exhibit 30 – Top-ranking solar thermal, wind power, and solar module companies

Solar Thermal		Wind Power		Solar Module	
Company	**Ownership**	**Company**	**Ownership**	**Company**	**Ownership**
Himin	Private, China	Vestas	Denmark	Jinko Solar	Private, China
Micoe	Private, China	Goldwind	China SOE	JA Solar	Private, China
Sunrain	Private, China	Siemens Gamesa	Spain	Trina Solar	Private, China
Linuo-paradigma	Private, China	GE	USA	LONGi Solar	Private, China
Haier	Collectively owned, China	Envision	Private, China	Canadian Solar	Canada
Tsinghua Solar	Collectively owned, China	Enercon	Germany	Hanwha Q-CELLS	South Korea
Sangle	Collectively owned, China	Mingyang	Private, China	Risen Energy	Private, China
Huayang	Private, China	Nordex	Germany	Talesun	Private, China
Tianpu	Private, China	Guodian United Power	China SOE	Tianpu	Private, China
Sunshore	Private, China	Sewind	China SOE	First Solar	USA

Source: *Adapted from Sheng, 2020, p.2, Table 1.*

4) Market formation: Policies are a fundamental piece of this function, because they set the basis to support the conditions to make a favourable environment for industry actors to take part in a new market. Also, policies are useful to overcome barriers such as the higher initial cost of installing generating capacity, restricted access to capital; and insufficient demand (Goess et al., 2015). For example, in the solar energy industry, thanks to the conditions promoted by the government through laws, programs and plans, it is possible to observe the generation of other industries that have been born as applications of solar energy. Specifically, the solar energy heat, this technology was born from solar energy and in turn gave rise to the market for solar water heaters and solar water installations. The same is the case in the solar energy building and solar cooker industries.

5) Resource mobilization: The technological development of the renewable energy industry requires economic resources, represented in both national investment (by the government of the People's Republic of China) as well as foreign investment. China - United States is an appropriate case to illustrate the collaboration between countries similar in magnitude and pollution activity and how they work together mobilizing human resources (researchers and experts) to generate, transfer and disseminate knowledge. According to the US Energy Information Administration (2021), China alone was responsible for over 80% of the increase in annual installations from 2019 to 2020, as onshore wind and solar PV projects worldwide.

6) Legitimation: This function is intricately linked to the reception of the community and the different stakeholders according to the development of renewable energies. From the point of view of the industry, a favourable response is observed thanks to the multiple initiatives of the government to encourage different entities to generate innovation, efficiency and technological development of the industry. From the point of view of the academy, the reception has also been positive, an example of this are the multiple associations with other governments, universities and companies to work together in favour of the energy transition. Finally, from the point of view of the communities, in general, the response has been positive due to the positive externalities generated. However, in some cases, the population has suffered the effects of progress, for example in places where hydroelectric plants have been installed and local communities have had to emigrate.

7) Development of positive externalities: Reducing negative effects on the environment by promoting the development of clean energy translates into positive externalities for Chinese society. On the one hand, positive externalities at the global level are manifested in market access. China has managed to build a highly competitive solar energy market, where the participating companies are highly efficient and offer good quality products at a much lower price than is observed in other markets such as North America. This, at the same time, increases China's exports to other countries and increases GDP. At the local level, positive externalities are also generated, breathing cleaner air, job creation and access to electricity, for all those private rural communities connected to the grid.

The above analysis brings powerful insights to this study regarding to the technological development of the renewable energy industry in China. First, is possible to realize that the government's efforts have been forceful and consistent with the objectives set to achieve the energy transition. In favour of decarbonization, national security and a better quality of life for its citizens. However, it is also observed that China still occupies the first position as the most polluting country in the world and continues to open coal plants, in 2020 opened three-quarters of the world's newly funded coal power plants (PHYS.ORG, 2021). This generates a mismatch with the government's goals of becoming carbon neutral by 2060. Therefore, despite the success achieved in the development of clean energy, thanks to the different innovation systems, it is difficult to envision a future with a carbon neutral China. This requires greater political commitment to lead the country towards this task, the action of civil society exerting greater pressure to mobilize the government and the commitment of the industry to contribute to the country beyond generating wealth.

4.5. China’s Regional Innovation System (RIS)

Before diving into China’s Regional Innovation Ecosystem, it is important to understand how the country’s administrative units are currently divided. China has 34 regions with different levels of political autonomy, which are classified into 2 special administrative regions, 4 municipalities, 5 autonomous regions, and 23 provinces, as detailed in the Exhibit 31 and Figure 05.

Exhibit 31 – China’s Administrative Division

Classification	Special Administrative Regions	Municipalities	Autonomous Regions	Provinces
Regions	Hong Kong Macao	Beijing Chongqing Shanghai Tianjin	Guangxi Inner Mongolia Ningxia Tibet Xinjiang	Anhui Fujian Gansu Guangdong Guizhou Hainan Hebei Heilongjiang Henan Hubei Hunan Jiangsu Jiangxi Jilin Liaoning Qinghai Shaanxi Shandong Shanxi Sichuan Taiwan Yunnan Zhejiang
Political Status	Autonomous and self-governing subnational areas of the People's Republic of China, so each region has its own chief executive and head of government.	Self-governing districts under the direct jurisdiction of the central government, however with political status higher to that of the provinces.	Regions with higher population of a particular minority ethnic group along with its own local government and some legislative rights, so the governor of each region is usually appointed from the respective minority ethnic group.	Are the standard administrative regions subordinated to China’s central government, led by a provincial committee headed by a secretary.

Source: *The State Council of China 2021.*

Figure 05: *Map of China.*

According to a joint-study made by the European Union (2021) through the International Urban Cooperation Policy between EU-ASIA, it is important to recall that, initially, China's innovation-related policies have not been focused on territories. Instead, the central government had leaded the agenda focusing on sectors with the aim of developing excellence in science and technology, and in empowering economic actors, enterprises and start-ups, in order to increase their added-value and global competitiveness. However, territorial strategies are not inexistent and, on the last decades, several efforts have been made to promote a more balanced development among regions and to ensure that sub-national regions are ready to benefit from innovation initiatives. For instance, it has been put emphasis on urbanisation, more autonomy given to regional governments to tailor central policies to their local reality, and integration efforts to engage major stakeholders at the regional/local level such as enterprises, universities, research institutes, and various coordination platforms/agents.

According to the platform China Innovation Funding EU (2021), local governments initiatives are currently executed at all levels, starting from the provincial-level, going through municipal-level, and ending with county-level and district-level governments. Furthermore, high-tech zones and industrial parks often also have their own programmes for actors established within their boundaries.

For instance, local funding programmes replicate the structure existing at the national level:

- Local S&T departments (local equivalents of the Ministry of Science and Technology) mainly fund projects focusing on R&D, technology demonstration, or basic/applied research.
- Local departments of economy and informatisation (local equivalents of the Ministry of Industry and Information Technology) mainly fund industrial/technological upgrading projects, purchase of new advanced equipment and products, etc.
- Local party bodies and foreign experts' administrations mainly fund talent recruitment and attraction programmes, such as localised versions of the 'Thousand Talents Plans'.

Local funding programmes are also generally divided into two typologies of programmes, one targeting local actors, and the other targeting international cooperation to which only foreign entities based overseas and not in China can participate in cooperation with a local actor which is the one submitting the application.

In terms of innovation performance, based on the level of R&D investment and patents granted, statistics shows that in 2018 the 6 main innovative regions in China were Guangdong, Jiangsu, Beijing, Shandong, Zhejiang, and Shanghai, that combined represented 59% of the country's domestic R&D investment and 61% of the domestic patents granted (see Exhibit 32). Furthermore, all these regions presented an impressive growth from 2000 to 2018, both on investment level and patents granted, such as Zhejiang which increased its R&D investment around 43 times, and Jiangsu which increased its domestic patents granted around 47 times at the period.

To corroborate the impressive development of the top 6 innovative regions, it is also important to identify their evolution in terms of population and GDP. For instance, consider for example the region of Jiangsu, which presented the highest shift from rural population to urban population, and the highest improvement in GRP (Gross Regional Product), both in absolute value and in per capita value from the years 2000 to 2018 (see details on Exhibits 33 and 34).

Exhibit 32 – China's regional statistics on R&D Expenditure and Patents Granted

Domestic R&D Inputs - Intramural Expenditure for R&D by Region (10,000 yuan)

Region	2000	2005	2010	2015	2018	Growth 2018 vs 2000
National Total	*8 956 645*	*24 499 731*	*70 625 775*	*141 698 846*	*196 779 294*	*22.0x*
Guangdong	1 071 166	2 437 605	8 087 478	17 981 679	27 046 969	25.3x
Jiangsu	729 995	2 698 292	8 579 491	18 012 271	25 044 293	34.3x
Beijing	1 556 635	3 820 683	8 218 234	13 840 231	18 707 701	12.0x
Shandong	519 501	1 951 449	6 720 045	14 271 890	16 433 300	31.6x
Zhejiang	333 538	1 632 921	4 942 349	10 111 792	14 456 893	43.3x
Shanghai	737 779	2 083 538	4 817 031	9 361 439	13 592 023	18.4x
Others	*4 008 031*	*9 875 273*	*29 261 189*	*58 119 550*	*81 498 116*	*20.3x*

Source: *data extracted on 16 July 2021 from China Data Insights, China Statistical Yearbook on Science and Technology.*

Domestic R&D Outputs - Domestic Patents Granted

Region	2000	2005	2010	2015	2018	Growth 2018 vs 2000
National Total	*95 236*	*171 619*	*740 620*	*1 596 977*	*2 335 411*	*24.5x*
Guangdong	15 799	36 894	119 343	241 176	478 082	30.3x
Jiangsu	6 432	13 580	138 382	250 290	306 996	47.7x
Zhejiang	7 495	19 056	114 643	234 983	284 621	38.0x
Shandong	6 962	10 743	51 490	98 101	132 382	19.0x
Beijing	5 905	10 100	33 511	94 031	123 496	21.9x
Shanghai	4 050	12 603	48 215	60 623	92 460	22.8x
Others	*48 593*	*68 643*	*235 036*	*617 773*	*917 374*	*18.9x*

Data Source: *extracted on 16 July 2021 from China Data Insights, China Statistical Yearbook on Science and Technology.*

Exhibit 33 – China's regional statistics on Population

Region	Population at Year-end (10,000 persons)		Population Distribution by Urban and Rural Residence			
			2000		2018	
	2000	2018	% Urban	% Rural	% Urban	% Rural
National Total	*126 743*	*139 538*	*36,9%*	*63,1%*	*59,6%*	*40,4%*
Guangdong	8 650	11 346	55,0%	45,0%	70,7%	29,3%
Shandong	8 998	10 047	38,0%	62,0%	61,2%	38,8%
Jiangsu	7 327	8 051	41,5%	58,5%	69,6%	30,4%
Zhejiang	4 680	5 737	48,7%	51,3%	68,9%	31,1%
Shanghai	1 609	2 424	88,3%	11,7%	88,1%	11,9%
Beijing	1 364	2 154	77,5%	22,5%	86,5%	13,5%

Data Source: *extracted on 16 July 2021 from China Data Insights, China Statistical Yearbook.*

Notes:

a) Total population exclude the military personnel

b) Data of 2000 and 2010 are the census year estimates; the rest are the estimates from the annual national sample survey of population.

c) Since 2005, data by region are of usual residents.

d) Data in the table are estimates from the 2018 National Sample Survey on Population Changes.

Exhibit 34 – China's regional statistics on GDP

Region	GDP (100 million yuan)			GDP Per Capta (yuan/person)		
	2000	2018	Growth	2000	2018	Growth
National Total	*99 066*	*919 281*	*9.3x*	*7 942*	*65 534*	*8.3x*
Guangdong	10 810	99 945	9.2x	12 817	88 781	6.9x
Shandong	8 278	66 649	8.1x	9 260	66 472	7.2x
Jiangsu	8 554	93 208	10.9x	11 765	115 930	9.9x
Zhejiang	6 164	58 003	9.4x	13 467	101 813	7.6x
Shanghai	4 812	36 012	7.5x	30 307	148 744	4.9x
Beijing	3 278	33 106	10.1x	25 014	153 095	6.1x

Source: *extracted on 16 July 2021 from National Bureau of Statistics of China.*

Notes:

a) Data are calculated at current prices.

b) According to China's regulations on the national accounts data revisions and international practice, systematic revisions are made on the Gross Regional Product (GRP) figures for 2018 and earlier years with the data from the fourth economic census available.

c) Due to rounding off, the sum of itemized data may not equal to the total data.

Moving forward, this study will focus on the Jiangsu province to analyse its regional innovation ecosystem in the last 10 years. This province is located on the east coast of China, bounded by the Yellow Sea to the east, Shanghai municipality to the southeast, and by the provinces of Zhejiang to the south, Anhui to the west, and Shandong to the north (see Figure 06). The provincial capital of Nanjing was the southern capital of China during the Ming dynasty (1368–1644) and the capital under the Nationalist government (1928–49). The other major cities of Jiangsu are Suzhou and Wuxi, both located along the Yangtze River.

Figure 06: *Map of Jiangsu Province.*

Jiangsu has been the economic and cultural centre of southern and southeaster China since ancient times, and it became a separate province in 1667. The province is now among the most economically developed provinces with an important industrial base. Jiangsu's 2020 key figures according to the National Bureau of Statistics of China (2021) are the following:

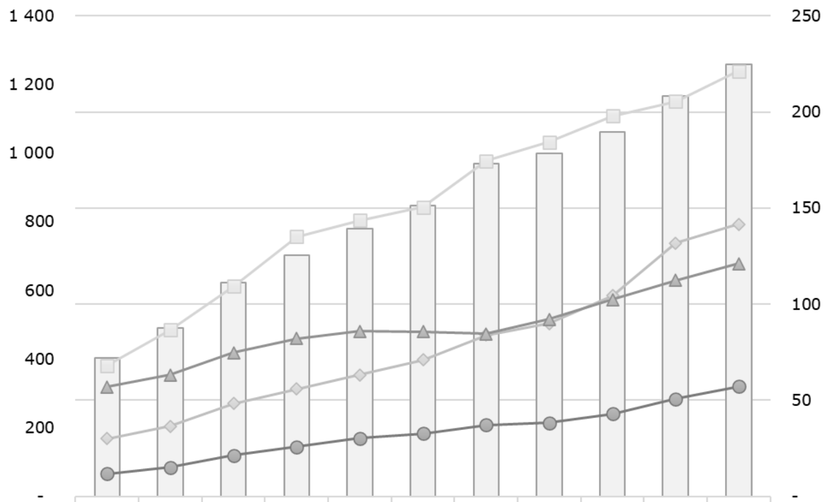
- *Land Area:* 107 200 km2
- *Population:* 84.8 million
- *Provincial Capital:* Nanjing
- *Gross Regional Product (GRP) Per Capita:* RMB 121 231
- *Total Gross Regional Product:* RMB 10 272 billion
    - *Value-added of the Primary Industry:* RMB 454 billion (4%)
    - *Value-added of the Secondary Industry:* RMB 4 423 billion (43%)
    - *Value-added of the Tertiary Industry:* RMB 5 396 billion (53%)

4.5.1. Jiangsu Government and Policies

Currently, Jiangsu counts with four main categories of public bodies dedicated to foster innovation and local development, namely: 1) the *Jiangsu Provincial S&T Department*, which is focused on projects involving R&D and the establishment of key innovation centres and facilities; 2) the *Jiangsu Provincial Industry and Information Technology Department*, which is focused on projects involving industrial upgrading, purchase and development of new equipment, etc.; 3) the municipal-level government initiatives, such as the *Nanjing Municipal S&T Commission*, the *Suzhou Municipal S&T Commission*, the *Wuxi Municipal Commission of Economy and Informatisation*, etc.; and 4) the *National Innovation Demonstration Zones*, and other industrial parks, such as the *Suzhou Industrial Park*, etc.

According to the National Bureau of Statistics of China (see details in the Exhibit 35), the local government of Jiangsu has increasingly focused on investing in S&T (Science and Technology), for instance, from 2009 to 2019 the general budgetary expenditure increased 3 times in absolute value while the expenditure in S&T increased 5 times at the same period, thus representing 4.5% of the government budget in 2019 (above the national average expenditure in S&T which was 4%).

Exhibit 35 – Jiangsu Local Government Budgetary Expenditure (RMB billions)



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
General Budgetary Expenditure	402	491	622	703	780	847	969	998	1 062	1 166	1 257
Education	68	87	109	135	143	150	175	184	198	206	221
Social Safety Net and Employment Effort	30	36	48	56	63	71	84	90	104	132	142
General Public Services	57	63	75	82	86	86	85	92	102	112	121
Science and Technology	12	15	21	26	30	33	37	38	43	51	57

Source: *data extracted on 18 July 2021 from National Bureau of Statistics of China.*

Among the main initiatives leaded by the government to foster local development and innovation in the Jiangsu province, several policies have been put in practice, namely: the establishment of *development zones*, the creation of *funding programs for innovation*, the creation of *funding programs for talent development and attraction*, and the establishment of *incentives for the development of the private sector* (the local industry).

The Establishment of Jiangsu main Development Zone

As previously explained within China's National Innovation System, the central government has created different programs for clustered development, which can comprise one or more of the following initiatives:

- *Industrial Parks:* which aims to attract foreign investment and capitalize on the low cost of labour within specific industries, also including benefits such as eliminating VAT and customs duties on products imported into these zones, as well as reductions in profits and other taxes realized by companies operating in these areas.
- *Demonstration Zones:* which are areas for international trade similar to the concept of *duty-free shops*, including sea, land and airports, intended to support imports, industry and consumption, as well as to boost trade innovation in policy, services, and models.
- *High-Tech Zones:* which concentrate high-tech industries, infrastructure, and talent in regional clusters that benefit from special government incentives such as lower tax rates.
- *National Innovation Demonstration Zones (NIDZ): which* serve as trial and experimental platforms for innovation policies, mainly related to equity and financial reforms, tax reduction and relief, and commercialisation of results in emerging high-tech industries.

For instance, the province of Jiangsu is a great example of a development zone which evolved its status encompassing different initiatives and currently representing one of the most important development zones in China. Jiangsu has achieved great success thanks to policies and financial support leaded by the national and local governments to attract enterprises and foster innovation (such as tax and bureaucracy reduction) as well by building an ecosystem of complementary industries, services, and infrastructure (including education, living conditions, and medical services) as shown in the Exhibit 36.

Currently, the *Nanjing Jiangning Economic and Technological Development Zone* embraces the *electronic information industry* and *automobile manufacturing industry* as the two leading sectors, also comprising complementary industries such as smart grid and power automation, software and service outsourcing, aerodynamic, and new energy. For instance, some key factors according to the zone's official website (Jiangning Development Zone, 2021) are:

- GDP and fiscal income growing on an annual rate of over 20%.
- More than 2000 projects attracted from USA, Germany, Japan, Korea, Taiwan, and Hong Kong (including more than 500 projects of over ten million US dollars).
- 52 world-top-500 enterprises have settled down in this development zone (such as Microsoft, Oracle, Ericsson, Motorola, Siemens, Philips, Ford, Volkswagen, Iveco, Thyssen Krupp, FedEx, DHL, among others).

Furthermore, the zone's education system counts with full-time kindergartens matching residential areas, 4 provincial pilot primary schools, 4 high schools and 15 colleges/universities including the principal campus of Southeast University, the Jiangning Campus of Hehai University, the General Road Campus of Nanjing University of Aeronautics and Astronautics.

Exhibit 36 – Jiangning Development Zone Milestones

Year	Milestones
1992	Establishment of the *Nanjing Jiangning Economic and Technological Development Zone* as a core area of the urban development of Nanjing (Jiangsu's provincial capital), starting as a county-run self-paid development.
1993	Approved as a *provincial development zone*.
1997	Approved by the National Scientific Commission as a high-tech industrial park.
2010	Approved by the State Council as a national economic and technical development zone to become an opening demonstration zone of Jiangsu Province, a concentration zone of foreign capital utilization, a high-tech industrial congestion area, and a pioneering area of S&T innovation.
2011	Approved as a central innovation and venture base for overseas high-level talents.
2013	Designated as the National Smart Grid industry famous brands creation demonstration area.
2014	Awarded the national study patriotic base and the national new energy demonstration industry park.
2019	Ranked 7th among the 219 national economic development zones in China.
2020	Ranked between China's top 10 industrial parks in international business environment.

Source: *Jiangning Development Zone 2021.*

The Establishment of Funding Programs for Innovation

In terms of funding policies for innovation and economic development established by the provincial government of Jiangsu, it is possible to identify complementary (and sometimes overlapping) initiatives leaded by different government bodies targeting from small to large enterprises, universities, and research institutes mainly related to high technology fields as shown in the Exhibit 37 (it worth mentioning that, complementarily to the provincial programs, some municipalities such as Nanjing, Suzhou, and Wuxi have their own versions of these initiatives).

Most of the funding programmes aim to reduce tax costs for enterprises and/or to provide subsidies for science and technology capabilities (such as equipment modernization, R&D, etc.). Some benefits are exclusive to certain status/classifications that enterprises can acquire by attending some criteria. Consider, for example, the HNTE status (High- and New-Technology Enterprise status), which is considered one of China's core innovation tax policies under China's Corporate Income Tax Law since the 1990s to encourage investment in high-tech and R&D areas through a series of benefits including fiscal and tax incentives. Normally, the specific areas funded vary every year and are specified in annual calls. Finally, the specific amount of funding will depend on the value of the project launched by the enterprise.

Exhibit 37 – Jiangsu's Main Provincial Funding Programs for Innovation

Policy Target	Responsible Government Body	Provincial Program
High-tech enterprises (especially MSMEs) with plans to apply to the HNTE status in the short-term	Jiangsu Provincial S&T Department	*Cultivation Fund* Supports the growth of medium and small enterprises that aim to apply to the HNTE status. Approved enterprises receive funding/subsidies according to their development needs to achieve the HNTE status and benefit from a significant reduction of Corporate Income Tax.
Enterprises (especially MSMEs) which have not been granted HNTE status	Jiangsu Provincial Finance Department	*Enterprise R&D Expenditure Reward Fund* Used to guide and encourage local enterprises to increase their investments in R&D (eligible enterprises receive a reward).
HNTE's, universities, and research institutes (joint applications from enterprises and universities are encouraged)	Jiangsu Provincial Development and Reform Commission	*Jiangsu Provincial Engineering Research Centre* Status given to certain Jiangsu-based entities with strong conditions and capacities for innovation, dedicated to market- and industry-oriented engineering R&D, verification, application and integration of core technologies in key areas. Approved enterprises receive financial support for the establishment of the facility and purchase of equipment, together with particular support when applying to other provincial- or national-level funding programmes.
Enterprises	Jiangsu Provincial Industry and Information Technology Department	*Jiangsu Industry and Information Technology Transformation and Upgrading Special Fund* A dedicated fund to boost the industrial transformation and upgrading of local enterprises, thus accelerating the quality and effectiveness of the province's economic development. Every year it grants compensations (subsidies, loan interest subsidies, awards) or paid support (equity participation, debt investment, etc.) to projects in five main areas: high-end industrial development; enterprise technology transformation; green development; productive service industry; and digitalisation and smartification.
Large enterprises	Jiangsu Provincial Industry and Information Technology Department	*Jiangsu Industrial Enterprise Technology Upgrading Project Compensation* An ad hoc programme to accelerate the upgrading of machinery and equipment of local enterprises, thus contributing to the supply-side reforms launched by both the central and the local government. The programme offers up to 10 million RMB to eligible technological upgrading projects launched by enterprises.
Enterprises, SMEs	Jiangsu Provincial S&T and Finance departments	*Jiangsu Provincial Technology Transfer Fund* Stimulates local enterprises to launch technology transfer and commercialisation projects within Jiangsu province, thus strengthening the link between scientific research and the industry and fostering economic development. Subsidies or grants are given to selected enterprises for expenses incurred during pilot production or commercialisation, for bank loan interest rates, or for the execution of certain tasks. The Fund is divided into two main programmes: Key industry programme: supporting projects in strategic key sectors such as ICT, intelligent manufacturing, high-end equipment, strategic materials, advanced energy, pharmaceuticals, etc. (sectors may vary every year); High-tech zones bidding programme: supporting local governments to join forces with high-tech zones to launch technology transfer projects on a larger scale (each area is assigned a certain number of projects every year).

Source: *European Union 2021.*

The Establishment of Programs for Talent Development and Attraction

In order to cope with the high demand for skilled professionals, entrepreneurs, innovators, and scientists/researchers, the province of Jiangsu has launched programs dedicated to talent development and attraction. Furthermore, similarly to the main policies for innovation previously mentioned, some municipalities in the province have also developed their own programs for talent development and attraction, including initiatives targeting oversea talents (see Exhibit 38).

Exhibit 38 – Main Programs for Talent Attraction and Retention

Program	Objective
Jiangsu Mass Innovation and Entrepreneurship Talent Programme	A dedicated programme for the recruitment of high-level innovation and entrepreneurship returnees or foreign talents. It offers financial support for conducting research or to start businesses in key industries, such as ICT, high-end software, biotechnologies, pharmaceuticals, new materials, high-end manufacturing, environment-friendly technologies, new energies, internet of things, aerospace and marine equipment, and digital industries.
Jiangsu Provincial Basic Research Programme (Natural Science Fund)	Established by the provincial government to support original innovative research in the field of natural sciences, and to contribute to talent growth, divided into: *General programme:* with no limits of specific research topic or field. *Young Scientist Fund:* for young scientists to conduct exploratory research. *Excellent Young Scholar projects:* designed to support talented young scholars who have successfully completed projects under the Young Scientist Fund. *Distinguished Young Scholar projects:* designed to support young scholars that have the potential to be selected, in the short-term, as National Distinguished Young Scholars (i.e. a particular category of the National Natural Science Fund).
Nanjing Entrepreneurship Talent Attraction Plan	Targeting Nobel prize winners, Chinese or developed countries academicians, winners of the national highest S&T award.
Nanjing 345 Overseas Talent Recruitment Programme	Targeting high-level innovation and entrepreneurship returnees or foreign talents to Nanjing, by offering subsidies, rewards and administrative support to both the recruiting entity and the talent.
Nanjing Rewards for High-Level Innovation and Entrepreneurship Talents	Offer rewards based on the contributions made to the local economy by Nanjing-based high-level innovation and entrepreneurship talents operating in one of the local priority industries (such as advanced manufacturing and future industries).
Nanjing Technology Transfer Revenue Rewards for Scientists	Rewards to Nanjing-based scientists for transferring, licensing, or outsourcing technology results (including patents), thus generating income and contributing to local economic development.
Suzhou S&T Development Plan – Innovation and Entrepreneurship Talent Programme	To support high-level innovation and entrepreneurship talents and teams to relocate to Suzhou for their activities. Financial support is granted to both the talent/team and the recruiting institution. Living and housing support may also be granted in case of entrepreneurs or talents working in enterprises. Priority is granted to talents/teams recruited in the areas of strategic and emerging industries (nanotechnologies, high-end machinery, intelligent manufacturing, new materials, new energy, green technologies, biology and medical devices, ICT), technology services, and modern agriculture.
Suzhou Overseas Intelligence Soft Recruitment "Seagull Plan"	Designed to recruit foreign talents to come to Suzhou-based entities for short-term cooperation projects, including consulting, trainings, etc., without affecting the foreign talent's relationship with his/her current employer. Cooperation projects in key strategic sectors are encouraged.

Source: *European Union 2021*

Incentives for the Private Sector

According to China Briefing (2019), the Jiangsu government aims by 2022 for private economic value-added growth to contribute over 60 percent of the province's total growth, private industrial output to contribute over 65 percent of total industrial output, and private capital investment to account for over 75 percent of total social investment. So, apart from the funding and talent programmes, the government proposed some key measures to foster the development of the private sector, namely:

- Adoption of the *negative list for market access* (which is a list that specifies prohibited and restricted markets, such as construction, accommodation and catering, finance, among others) and encouraging and guiding private capital to invest in all sectors and business areas not explicitly outlawed.
- Opening more markets to private and foreign investors, such as railways, civil airports, basic telecommunications, electricity allocation and sales, defence-related science and technology, and finance.
- Introducing infrastructure and Public Private Partnership (PPP) projects to private companies. For provincial-level PPP projects where private capital is significant, the standard of landing bonus and subsidy will increase by 10 percent.
- Spending at least 40% of the total annual procurement budget of provincial departments on goods and services provided by private enterprises, especially by SMEs.
- Supporting private enterprises to participate in the restructuring and reorganization of state-owned enterprises by means of equity participation, holdings, and asset acquisition.
- Pushing for no less than one-third of new corporate loans for private enterprises to come from large banks and no less than two-thirds to come from small and medium-sized banks.

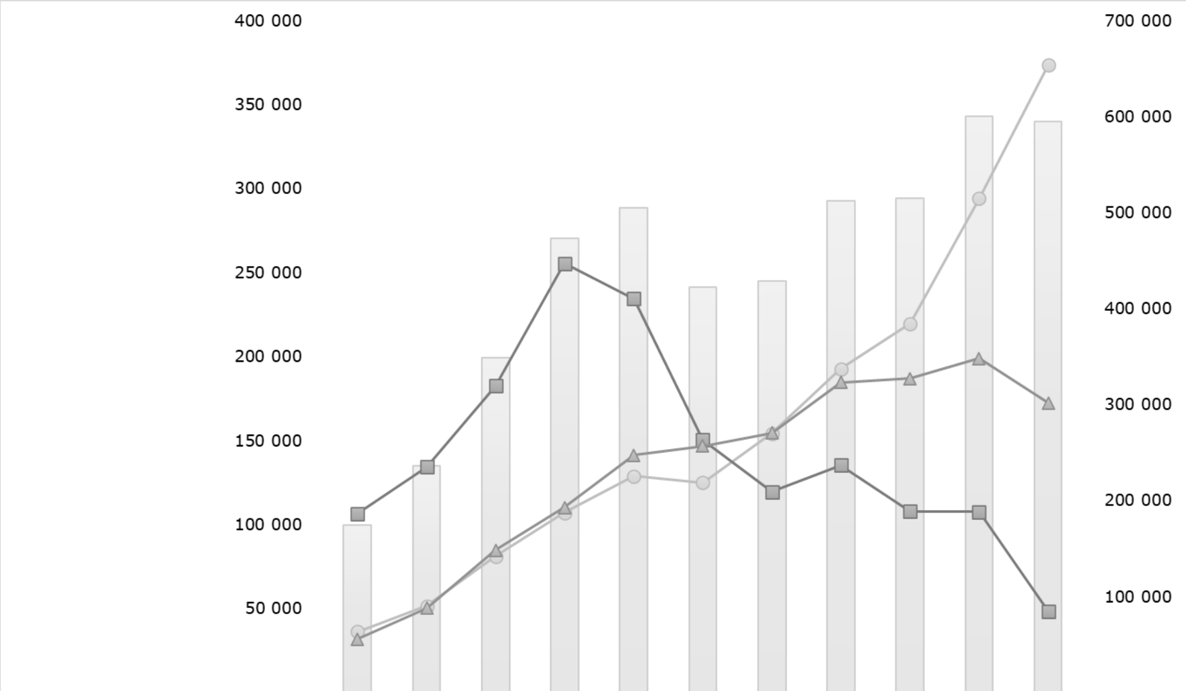
Jiangsu's results on patents

To conclude the regional government and policy section, this study presents patent data as a key indicator of innovative performance. Some may argue that the analysis of patents to evaluate the rate of innovation is subject to limitations (because not all inventions are patented, and not all the patented inventions are equal in quality), so this research partially addresses this limitation by presenting the patent data by category according to the China's patent classification (CNIPA, 2013):

- *Invention:* New technical solution relating to a product, a process or improvement.
- *Utility Model:* New technical solution relating to the shape, the structure, or their combination, of a product, which is fit for practical use.
- *Design:* New design of the shape, the pattern or their combination, or the combination of the colour with shape or pattern, of a product, which creates an aesthetic feeling and is fit for industrial application

For instance, as shown in the Exhibits 39 and 40, the province of Jiangsu has presented an impressive growth on the annual volume of domestic patents applications and patents granted from 2009 to 2019. For instance, when observed by category, the annual volume of domestic patents classified as a utility model grew 10 times comparing 2019 versus 2009.

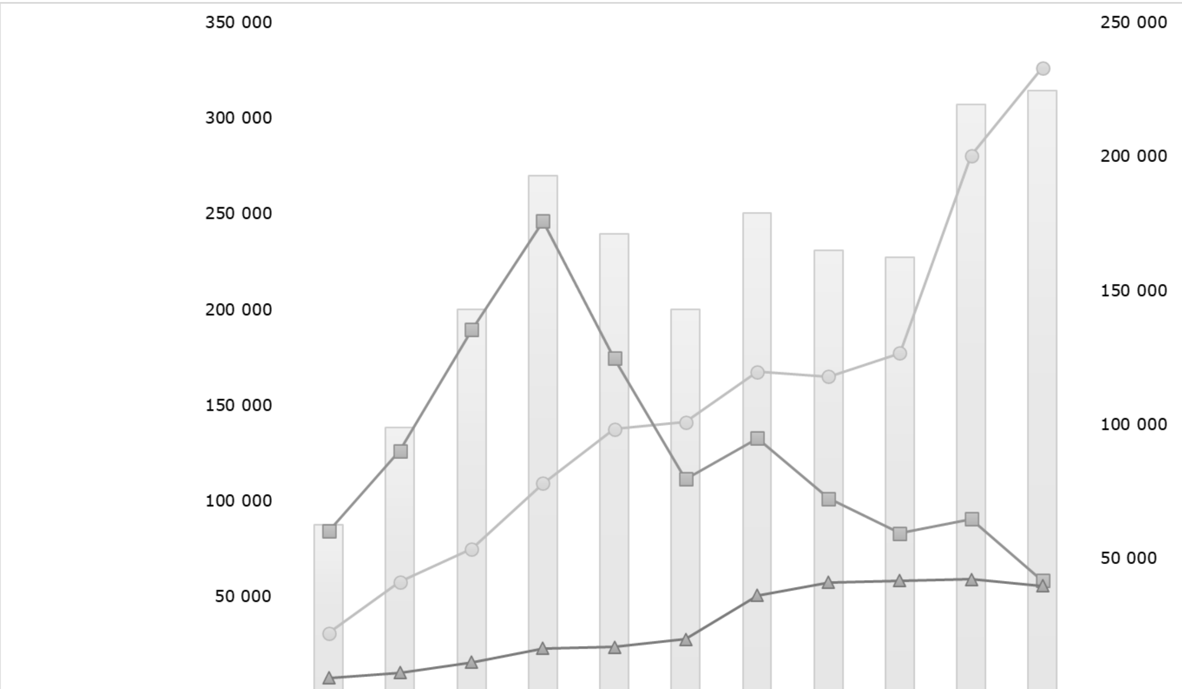
Exhibit 39 – Jiangsu Domestic Patents Applications Accepted (by unities/items)



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
All Domestic Patents Applications	174 329	235 873	348 381	472 656	504 500	421 907	428 337	512 429	514 402	600 306	594 249
Patents for Utility Models	36 122	51 436	81 097	107 091	128 898	124 980	154 281	192 636	219 503	294 090	373 495
Patents for Designs	106 428	134 139	182 606	255 474	234 343	150 267	119 448	135 161	107 894	107 415	48 345
Patents for Inventions	31 779	50 298	84 678	110 091	141 259	146 660	154 608	184 632	187 005	198 801	172 409

Source: *data extracted on 18 July 2021 from National Bureau of Statistics of China.*

Exhibit 40 – Jiangsu Domestic Patents Granted (by unities/items)



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
All Domestic Patents Granted	87 286	138 382	199 814	269 944	239 645	200 032	250 290	231 033	227 187	306 996	314 395
Patents for Utility Models	21 939	41 161	53 413	77 944	98 246	100 810	119 513	117 827	126 482	200 333	233 114
Patents for Designs	60 025	90 011	135 358	175 758	124 609	79 551	94 762	72 254	59 187	64 644	41 600
Patents for Inventions	5 322	7 210	11 043	16 242	16 790	19 671	36 015	40 952	41 518	42 019	39 681

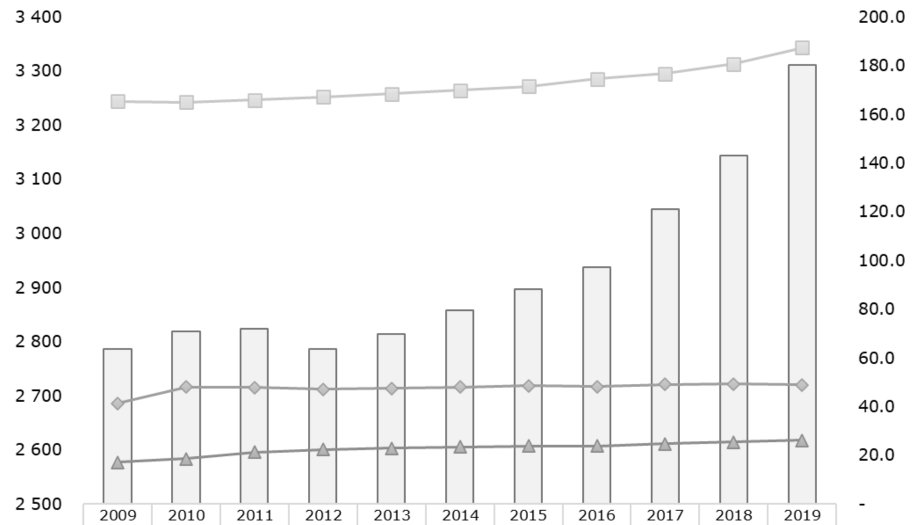
Source: *data extracted on 18 July 2021 from National Bureau of Statistics of China.*

4.5.2. Jiangsu Academia

Jiangsu Province has the third largest number of international students in China, and its educational landscape is considered among the top in China with many famous universities located in Nanjing, Xuzhou, Suzhou and Yangzhou City (Study in Jiangsu, 2021).

According to data from the National Bureau of Statistics of China (2021), the number of higher education institutions has increase from 148 in 2009 to 167 in 2019 (13% growth), while the number of students enrolment, the number of graduates, and the number of degrees conferred increased 13%, 18% and 52% respectively at the same period (see Exhibit 41). Furthermore, the advancements on higher education coverage overcame the resident population growth, thus representing an important increase at the level of skilled workforce in the Jiangsu province.

Exhibit 41 – Jiangsu Statistics on Higher Education Institutions



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Students per 100 000 Population	2 786	2 819	2 824	2 786	2 814	2 858	2 896	2 937	3 045	3 143	3 311
Students Enrollment (10000 persons)	165.3	164.9	165.9	167.1	168.5	169.9	171.6	174.6	176.8	180.6	187.4
Graduates (10000 persons)	41.3	47.9	47.7	47.0	47.4	47.9	48.4	48.2	49.0	49.1	48.9
Degrees Conferred (10000 persons)	17.2	18.4	21.2	22.3	22.8	23.4	23.8	23.8	24.6	25.4	26.1

Source: *data extracted on 18 July 2021 from National Bureau of Statistics of China.*

The most important university is the Nanjing University (NJU), which was founded in 1902 and currently is under the direct supervision of the Ministry of Education. The institution hosts some of the most important bodies of R&D and innovative activities which works integrated with all Government levels (local, regional, and national) as well with several players of the private industry.

Furthermore, NJU leads the agenda towards collaborative innovation by conducting several coordinative and supportive initiatives, such as recruiting high-level talents, establishing and promoting advanced research capabilities, spinning-off innovative technologies, training scientists and researchers, providing infrastructure to enterprises and inventors to test high-tech applications, engaging with national and international stakeholders to develop regulations and standards, etc. These activities and many others are executed by R&D institutions leaded by the NJU (either solely or jointly with other stakeholders from academia, government, and the private sector); each of these R&D institutions is focused on different fields, as listed in the Exhibit 42.

Exhibit 42 - Nanjing University R&D Institutions

Classification (status)	Institutions (fields)
Collaborative Innovation Centres	Advanced Microstructure Climate Change Novel Software Technology and Industrialization Regional Economic Transition and Management Transformation Solid-State Lighting and Energy-Saving Electronics South China Sea Studies
Engineering Research Centres	Environmental Protection National Engineering Research Centre National-Local Joint Engineering Research Centre Protein and Peptide Provincial Energy-Saving Semiconductor Devices and Materials Provincial Land Development and Management Provincial MicroRNA Engineering and Technology Research Provincial New Refrigeration Technology Surface and Interface Chemistry Engineering Technology Technology Centre for Testing and Validation of Internet of Things Water Treatment and Restoration of Water Environment
Institutes	Low-carbon Utilization of Biomass Energy Optical Communication Engineering and Network Engineering Rural Environment Protection and Ecological Restoration Software Engineering Global Institute for Innovation & Entrepreneurship
Laboratories	Coast and Island Development Data Engineering and Knowledge Service Electromagnetic Wave of Jiangsu Province Geographic Information Technology High Performance Polymer Materials and Technology Mesoscale Severe Weather Mesoscopic Chemistry Model Animals and Diseases Research Modern Acoustics Modern Astronomy and Astrophysics Molecular Medicine Nano Technology National Laboratory of Analytical Chemistry for Life Science National Laboratory of Microstructures (Under Construction) National Laboratory of Solid-State Microstructures National Resource Centre for Mutant Mice of China Non-Grid Connected Wind Power and High Energy-Loaded Engineering Photonic and Electronic Materials Sciences and Technology Reducing of Automobile Exhaust Fumes State Key Laboratory for Mineral Deposits Research State Key Laboratory of Coordination Chemistry State Key Laboratory of New Software Technology State Key Laboratory of Pharmaceutical Biotechnology State Key Laboratory of Pollution Control and Resource Reutilization Surficial Geochemistry

***Source**: Nanjing University 2021.*

More specifically, consider for example the *Collaborative Innovation Centre of Advanced Microstructures*, which concentrates on interdisciplinary research on advanced and artificial microstructure materials where micro/nano scale features give rise to novel properties, which can be exploited for a range of technological applications. For instance, the centre is currently responsible for 60 major national research projects with a total research budget of RMB 380 million (approximately USD 62 million).

Another key institution, the *Global Institute for Innovation & Entrepreneurship at NJU*, offers several trainings for industry and entrepreneurs, such as:

- Entrepreneurship and Innovation Education for Students
- Training for Start-ups
- Training for University Faculty Specializing in Entrepreneurship Education
- Training for Executives of Incubator Centres
- Innovation Capability Training for Party & Government Officials
- Bespoke Internal Training for Tech Companies

Finally, in terms of collaboration within the academia, the NJU has partnership with 196 so-called *Sister Universities* from 56 countries, mainly: the USA, the UK, South Korea, Australia, Japan, Germany, Pakistan, Ghana, and Canada.

4.5.3. Jiangsu Industry

In this section, this study focuses on presenting statistics from the industry and private companies at the Jiangsu province, which can be considered the main actor in terms of execution, production and scaling up innovation (thus increasing the region's competitiveness and economic development). On other hand, as presented previously, the government has an important leadership role in terms of innovation sponsorship and guidance (thus establishing priorities and rules, and providing financial support), while the academia adopts a more coordinative and networking role (thus supporting stakeholders through joint efforts for innovation and entrepreneurship).

To begin with, according to a report from the Hong Kong Trade Development Council (2021), Jiangsu's main industries are electronics, telecommunications, chemicals, machinery and equipment, textiles and garment, and metallurgy. On other hand, technology-intensive industry and capital-intensive industries (such as electronic and telecommunications) have been developing fast and the province is moving towards the development of new and high technology products. This trend is confirmed by the data from the National Bureau of Statistics of China as shown in the Exhibit 43, for instance, the 5-years accumulated output of mobile telephones and integrated circuits has grown 102% and 79% respectively when comparing the period of 2010-2014 versus 2015-2019.

When analysing the international trade from the Jiangsu province, it is possible to identify that the annual trade of commodities has increased 86% comparing 2019 versus 2009, however, the foreign-funded enterprises are behind in this matter, presenting an evolution of 45% at the same period, thus the domestic enterprises are ahead in this matter (see details on Exhibit 44).

Exhibit 43 – Jiangsu Province Output of Industrial Products

Indicators	Total Output from 2010 to 2014	Total Output from 2015 to 2019	Growth %
Output of Mobile Telephones (10000 sets)	13 100	26 415	102%
Output of Integrated Circuits (10000 pieces)	13 551 000	24 218 983	79%
Output of Primary Plastic (10000 tons)	3 888	5 847	50%
Output of Home Washing Machines (10000 sets)	6 549	9 512	45%
Output of Crude Steel (10000 tons)	39 167	54 943	40%
Output of Chemical Pesticides (10000 tons)	370	493	33%
Output of Soda Ash (10000 tons)	1 569	1 998	27%
Output of Motor Vehicles (10000 units)	472	580	23%
Output of Chemical Fibre (10000 tons)	6 046	7 198	19%
Output of Rolled Steel (10000 tons)	55 809	65 684	18%
Output of Pig Iron (10000 tons)	30 169	35 494	18%
Output of Cars (10000 units)	253	296	17%
Output of Ethylene (10000 tons)	706	813	15%
Output of Machine-made Paper and Paperboard (10000 tons)	5 997	6 585	10%
Output of Color Television Sets (10000 sets)	6 367	6 721	6%
Output of Air Conditioners (10000 sets)	2 327	2 296	-1%
Output of Caustic Soda 100% (10000 tons)	1 754	1 729	-1%
Output of Cement (10000 tons)	85 290	83 937	-2%
Output of Cloth (100 million m)	654	635	-3%
Output of Metal-cutting Machine Tools (10000 sets)	46	42	-8%
Output of Home Refrigerators (10000 sets)	5 114	4 633	-9%
Output of Sulfuric Acid 100% (10000 tons)	2 056	1 699	-17%
Output of Chemical Fertilizers (10000 tons)	1 299	932	-28%
Output of Micro Computer Equipment (10000 sets)	41 864	29 061	-31%
Output of Large and Medium Tractors (10000 sets)	44	29	-35%
Output of Plain Glass (10000 weight cases)	31 558	15 550	-51%

Source: *our analysis, based on data extracted on 20 July 2021 from National Bureau of Statistics of China.*

Notes:

a) The output of chemical fertilizers is calculated on the basis of 100 % effective content.

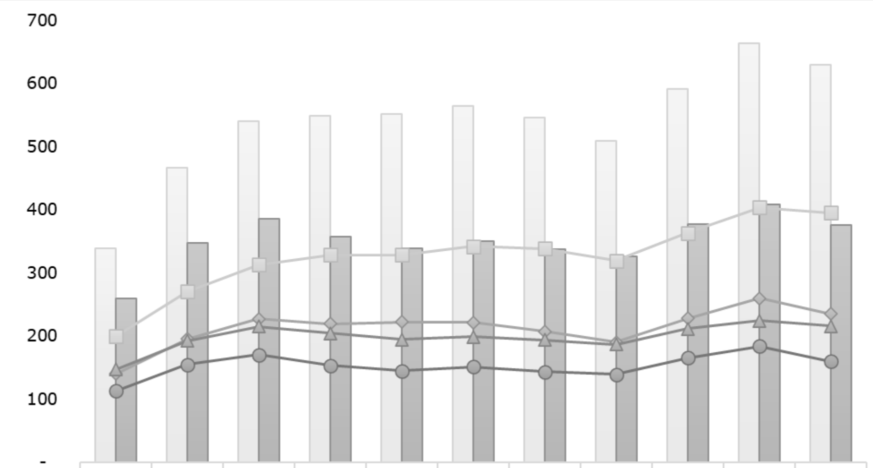
b) Metal-cutting machine tools do not include bench drills, grinders and polishing machines.

c) Before 2004, the primary plastic was called plastic colophony copolymer, or plastic in abbreviation.

d) Cloth includes pure and blended cotton, pure chemical-fibre and canvas, but excludes substitute fibre cloth, hand-woven cloth and cord fabric.

e) Tractors refer to both wheel and crawler tractors with a haulage capacity of 14.7 kw and over. The tractors which are refitted into bulldozers by the same tractor factories are deducted.

Exhibit 44 – Jiangsu Total Value of Imports and Exports Commodities (billion dollars)



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Foreign Trade of operating units	339	466	540	548	551	564	546	509	591	664	630
Foreign Trade Foreign-funded Enterprises	260	347	385	358	339	350	337	326	377	408	375
Exports of operating units	199	271	313	329	329	342	339	319	363	404	395
Imports of operating units	140	195	227	219	222	222	207	190	228	260	235
Exports of Foreign-funded Enterprises	147	192	215	205	194	199	194	187	211	224	216
Imports of Foreign-funded Enterprises	113	155	170	153	145	151	143	139	165	184	160

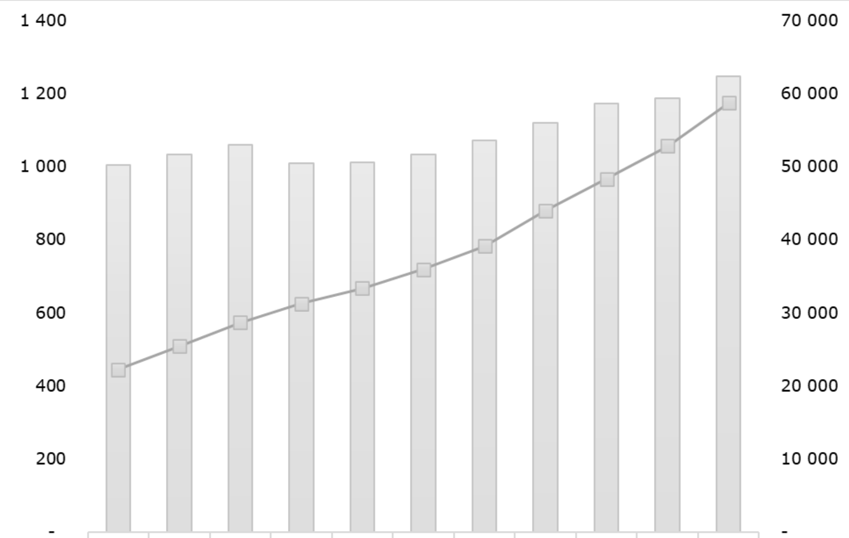
Source: *data extracted on 20 July 2021 from National Bureau of Statistics of China.*

Note: *Data are calculated at current prices. Data of import and export are from the general administration of customs.*

According to the Hong Kong Trade Development Council (2021), in recent years, major exports from Jiangsu included electronic and mechanical products, new and high technology products, automatic data processing machines & accessories, garments and clothing accessories. In 2020, the export value of electronic products amounted to 67% of total export value (major export markets included the US, ASEAN countries, Hong Kong, Japan and South Korea; on other hand, major imports included electronic and mechanical products, high technology products, integrated circuit and liquid crystal display panel, mainly from South Korea, Taiwan and Japan).

When looking at the level of foreign investment in Jiangsu, the number of enterprises increased 24% comparing 2019 versus 2009, while the total investment from those companies grew 164% at the same period (see details on Exhibit 45). This trend reflects how successful have been the incentive polices in terms of FDI attraction, not only in terms of quantity (such as the number of foreign funded enterprises), but especially in terms of intensity, thus fostering higher levels of investment. Furthermore, according to the Hong Kong Trade Development Council (2021), foreign investments in Jiangsu are still mainly engaged in the manufacturing sector, particularly in telecommunication equipment, computer, machinery, chemical products and textiles. In 2019, utilised foreign direct investment (FDI) in the manufacturing sector amounted to US$12.7 billion, accounting for 48.8% of the total FDI.

Exhibit 45 – Registration of Foreign Funded Enterprises (year-end)



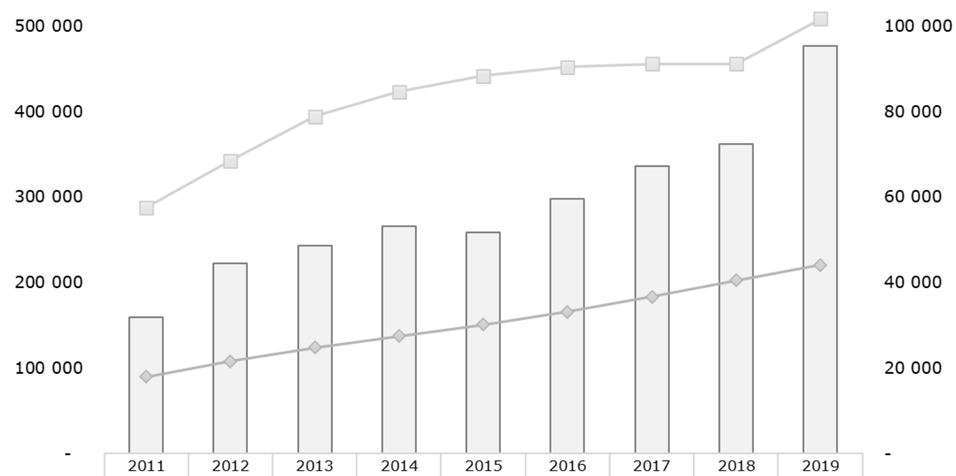
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Number of Foreign Funded Enterprises (unit)	50 241	51 666	52 959	50 461	50 514	51 634	53 551	55 938	58 577	59 308	62 360
Total Investment of Foreign Funded Enterprisies (USD billion)	444	508	573	625	666	718	782	880	966	1 056	1 174

Source: *data extracted on 20 July 2021 from National Bureau of Statistics of China.*

Notes:
a) Data are calculated at current prices
b) Data of foreign funded enterprises come from State Administration for Industry & Commerce of the People's Republic of China, and their number of registered enterprises includes enterprises and their sub-branch since 2008, and the figures before were adjusted too.

Finally, in terms of R&D inputs and outputs from the industrial sector, statistics are aligned with the previous trends, thus presenting an increasing volume both in investments and revenue as shown in the Exhibits 46 and 47.

Exhibit 46 – Statistics on R&D Activities of Industrial Enterprises

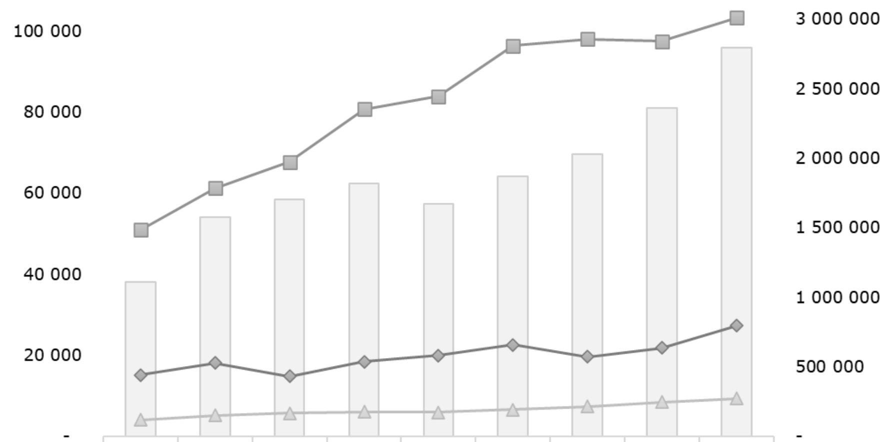


	2011	2012	2013	2014	2015	2016	2017	2018	2019
R&D Projects (item)	31 933	44 570	48 530	53 117	51 720	59 535	67 205	72 426	95 240
FTE of R&D Personnel (man-years)	287 447	342 262	393 942	422 865	441 304	451 885	455 468	455 530	508 375
Expenditure on R&D (million yuan)	89 989	108 031	123 957	137 654	150 651	165 754	183 388	202 452	220 616

Source: *data extracted on 20 July 2021 from National Bureau of Statistics of China.*

Note: *Data are calculated at current prices. From 2011, the statistics range of the industrial enterprises above designated size change from the industrial enterprises with the sales revenue above 5 million RMB to the industrial enterprises with the sales revenue above 20 million RMB.*

Exhibit 47 – Statistics on New Product Development of Industrial Enterprises



	2011	2012	2013	2014	2015	2016	2017	2018	2019
Number of New Products (units)	38 009	53 973	58 353	62 306	57 204	64 029	69 653	80 921	95 797
Expenditure on NPD (million yuan)	118 244	149 451	166 932	176 491	171 174	190 903	215 065	246 809	270 131
Sales Revenue of NP (million yuan)	1 484 211	1 784 542	1 971 421	2 354 093	2 446 327	2 808 467	2 857 902	2 842 504	3 010 194
Export Sales Revenue of NP (million yuan)	439 289	527 278	431 987	536 247	581 042	658 375	570 811	634 933	795 602

Source: *data extracted on 20 July 2021 from National Bureau of Statistics of China.*

Note: *Data are calculated at current prices. From 2011, the statistics range of the industrial enterprises above designated size change from the industrial enterprises with the sales revenue above 5 million RMB to the industrial enterprises with the sales revenue above 20 million RMB.*

To conclude, the statistics presented on this study about the Jiangsu industry and private enterprises corroborate the successful approach from the province's government and academia in supporting companies to boost innovation, investment (including FDI), and economic development. The empirical evidence presented confirm the importance of integrated and coordinated efforts with the Triple-Helix dimensions (Government-Academia-Industry) in order to foster innovation, technological and economic development in a regional context.

5. Conclusions

Innovation and its dynamics have grown over the past few decades, primarily due to its importance for the development and competitiveness of nations, but also due to the increasing complexity and dynamism of a globalized world. In the era of learning and knowledge, it is crucial to understand how innovation takes place, how different actors interact, and which factors can enhance the development and exchange of technological and scientific knowledge.

The purpose of the present research was to develop a comprehensive understanding of one of the most complex phenomena of the 21st century, the extraordinary economic development of the People's Republic of China in the last two decades. Innovation is the cornerstone of development, it is a process which requires the interaction of different actors in order to generate, transfer, and diffuse knowledge, thus it is the main issue studied in this thesis. Innovation systems are the infrastructure and dynamics within stakeholders, which combined provide the conditions to innovation to occur, thus being crucial for innovation development.

Overall, China's position as a leader in innovation and economic growth is the result of a systematic effort led by the government as from 1980. Since then, China has opened to international markets and set out to modernize its economy. In the same decade, the government realized that to achieve this goal, technological development and industry modernization was essential. That is why different programs are born to lay the foundations for future development in terms of innovative capacity. The programs are the heart of development, based on them the policies presented in the Five-Year Plans are put in practice to foster innovation. It is interesting to observe the correct and effective execution with which the policies are carried out, as clear evidence of the rigor of China's government toward rapid social economic development.

At the national level, the government stands out for its leadership, although the literature indicates that the role of the industry is the most preponderant as the actor who produces and commercializes innovation, while the government plays a coordination role in developing policies to foster innovation, and then academia plays a support role on creating knowledge such as basic science and skilled workforce. The findings show that, in the case of China, government action predominates over industry and academia. This is because it adopts not only a coordination role, but also provide the conditions that facilitate innovation in terms of resources, whether human or financial. Proof of this is the policy implemented by the government related to the development of talent, to have a qualified workforce and accelerate the development of the high-tech industry. In addition, it is known to be the government's efforts that have improved the intellectual property rights protection in China. Furthermore, statistic evidence shows that together with the increase in total GDP and per capita GDP, the industry that has generated the most advances in the last twenty years corresponds to the tertiary sector. Nothing of this could have been possible without the strong action of the national government, consequently, China is steadily moving from being a developing country to becoming a developed economy.

At the sectoral level, this study focuses on the development of renewable energy in China. Literature shows that through the aggregative analysis of complementary and sector-specific knowledge and technologies, policymakers and the actors within the innovation ecosystem enable the right conditions for a specific industry/segment development. However, unlike the national analysis, under the sectoral perspective, the industry plays a preponderant role. The industry exercises leadership over other actors, since firms are the basic and essential unit in the development of new technologies, products, and services.

The industries of the sector driven by the monetary incentive of the market and the support of the government are attracted to participate in the Chinese renewable energies market. It is observed that the industry is not only made up of state companies, but that the majority corresponds to foreign capital. The government acts as an integrator of stakeholders to overcome industry obstacles such as high cost of development, small market segment, and weakness in the manufacturing industry. In the case of academia, its role is crucial for the dynamics that are generated within the network: universities and scientific institutions act as bridges between the multiple nodes promoting the transfer of knowledge throughout the sectoral network. The renewable energy sector is not limited to a geographical region or country, it crosses borders to connect with foreign companies, universities, and government entities, that are at the forefront in the technological development of the sector.

Regional Innovation Systems approach provides a more practical view over the autonomy of regional/local governments to develop the policies and conditions for their own innovation ecosystems, and it also highlights the importance of geographical distance in innovation development, because spatial proximity is considered a key condition to allow the actors to interact, collaborate, learn, and share knowledge (both technical/scientific and tacit). The findings of this research indicate that industry is considered the main actor in terms of execution, production, and scaling up innovation (thus increasing the region's competitiveness and economic development). Evidence also points out that the autonomy of local governments to direct their innovation efforts really matters. Although the central government establishes the key programs, the local government has some authority and autonomy to determine investment in science and technology. In this sense, the government has an important leadership role in terms of innovation sponsorship and guidance (thus establishing priorities and rules, and providing financial support), while the academia adopts a more coordinative and networking role (thus supporting stakeholders through joint efforts for innovation and entrepreneurship). It is important to note that the political-administrative organization of the Chinese regions favours the development of innovation, these subdivisions allow greater efficiency when implementing the policies of the central government, since the local government, being a much smaller subdivision, has the ability to monitor and adapt national guidelines according to their specific needs.

Furthermore, it is important to notice that since 2012 the central government has published a number of opinions and policy documents emphasizing the role of enterprises as drivers of innovation activities, and regions as key clusters to speed up the transformation of S&T outputs into actual productive power. For this reason, while maintaining a key role by defining the innovation agenda, the central government has over time increased the autonomy of regional/local governments to tailor policies according to their features. Consider for example the Jiangning Development Zone (Jiangsu province), which started as national program and later on received the status of provincial development zone. Finally, the central government aims also to reduce the performance gap between regions (in 2018, for example, 6 regions among a total of 34 concentrated around 60% of all R&D expenditure and domestic patents granted), and for that to happen it is crucial to combine national guidance/support with regional autonomy.

The analysis of economic development and innovation in China on the last two decades, using the frameworks of innovation systems, specifically from the perspective of the triple helix at the national, sectoral, and regional levels, generates certain implications that need to be specified.

First, the main methodological implications, the application of the triple helix framework in these three scenarios allows comparison from different levels. This, in turn reflects the dynamics and roles that each actor adopts in each of the levels of analysis. On the other hand, all the approaches come together through the lens of network interaction and dynamic boundaries within nations, regions, and sectors. Therefore, this methodology provides a complete overview and deep understanding of the innovation process, which is highly useful to analyse complex phenomenon. For instance, a specific technology may be promoted by a national policy, then concentrated in a specific region due to favourable local conditions, and then exploited by specific sectors that depend heavily on this innovation. Ultimately, this same technology may represent a competitive advantage to the country enabling networking overseas, leading to international trade development, cross-national R&D partnerships, and increased inflow and outflow of knowledge and resources to continuously foster innovation.

Second, regarding theoretical implications, according to the analysis applied to China, it is observed that what the theory supports in terms of dynamics and roles of the different actors in the ecosystem, in reality it is not always reproduced in the same way. For example, according to the triple helix theory, the university stands out as the main actor, exercising an entrepreneurial role in the process of innovation and knowledge development. However, in the practice of Chinese reality, the academy occupies an important role, but it is not the one who leads. These differences are explained by the specific cultural and political characteristics of China. For instance, the collectivist approach of Chinese society expressed in its communist political system addresses the way of interaction between their citizens, their vision and respect to authorities, and exerts a great influence on the execution of the guidelines established by the government.

Third, regarding practical implications, currently the world faces great challenges to reduce its carbon emissions and combat climate change, China is not the exception, but on the contrary. The Asian giant has emerged as the most polluting country since 2007 and this situation directly affects the lives of Chinese citizens. Climate change has forced the world to change to save itself, this study provides practical implications regarding this particular issue. It is an example for other undeveloped but smaller economies to illustrate what must be done to achieve sustainable development, thus providing clear examples of good practices in terms of specific policies and programs to promote a suitable environment for innovation. Therefore, this paper provides useful insights for policymakers and people in high positions in international companies who wants to understand China’s current situation and to assess the key measures to properly foster the high-tech industry development. On the other hand, this study does not provide solutions to combat the imbalances present in Chinese society, nevertheless, it provides knowledge and initiatives that can be adjusted to the specific needs of each country. Furthermore, it constitutes convincing proof for the scientific and global community of the importance of investing a significant amount of the national budget in research and development to enhance innovation and economic development.

Due to the nature of the research methodology adopted for analysing the historical developments of China's innovation ecosystems, this study presents some limitations.

First, the qualitative information and events presented may be subject to bias since the main source of those were institutions interested in promoting their successful initiatives to build a positive reputation (such as the Chinese government itself for example).

Second, it is not possible to generalize the research findings (including quantitative ones), since the samples were based on limited success cases without amplitude/variety for broader statistical measurement of correlation or causation. Furthermore, there is no consensus on the literature about the exact extent of KPIs that must be applied to measure innovative performance in different contexts, or to determine which factors may have greater/lesser impact.

Finally, due to time constrains versus the magnitude of the research coverage (encompassing national, sectorial, and regional dimensions of complex innovation ecosystems in a broad timeframe from 10 to 20 years), combined with the authors' lack of knowledge of the Mandarin language, it may be possible that some relevant events and/or data was not contemplated.

Overall, the events, data, and findings presented in this study are useful to bring light to a broad understanding of China's innovation ecosystems. In this matter, future studies can benefit from these learnings and add value by conducting specific/focused research such as statistical contrast analysis between different regions or sectors. On other hand, at the national dimension, future research can be done by contrasting China's innovative performance in different years and identifying the factors (and extent of impact) which may lead to it.

This study focused on China's innovation ecosystems to explain the country's impressive development in this matter in a fast-paced fashion never seen before, but it can be enlarged by considering also other countries. Additional efforts might be conducted to discover which factors present greater impact on innovative performance at different realities and country profiles. Specifically, future research is suggested to analyse the influence of country-specific factors on the development of innovation, such as idiosyncrasies and culture, political and economic stability, and political regime.

6. References

Acs, Z. J., Anselin, L., Varga, A. (2001). Patents and innovation counts as measures of regional production of new knowledge. *Research Policy 31*, pages 1069-1085. https://doi.org/10.1016/S0048-7333(01)00184-6

Ang, J., Cheng, Y., Wu, C. (2014). Does Enforcement of Intellectual Property Rights matter in China? Evidence from financing and investment choices in the High-Tech evidence from financing and investment choices in the high-tech industry. *The Review of Economics and Statistics*, May 2014, 96(2): 332–348. http://www.jstor.org/stable/43554934

Asheim, B.T., Coenen, L. (2005). Knowledge bases and regional innovation systems: Comparing Nordic clusters. *Research Policy 34*, pages 1173-1190. https://doi.org/10.1016/j.respol.2005.03.013

Australian Government (2021). Australia-China Science and Research Fund–Joint Research Centres. https://www.industry.gov.au/funding-and-incentives/collaborating-with-china-on-science-and-research/australia-china-science-and-research-fund-joint-research-centres (acessed on 16 July 2021).

Balzat, M., Hanusch, H. (2004). Recent trends in the research on national innovation systems. *Journal of Evolutionary Economics 14*, pages 197-210. https://doi.org/10.1007/s00191-004-0187-y

Balzat, M., Pyka, A. (2005). Mapping National Innovation Systems in the OECD Area. *Volkswirtschaftliche Diskussionsreihe, No. 279*, Universität Augsburg, Institut für Volkswirtschaftslehre, Augsburg. http://hdl.handle.net/10419/22802

Berg, B.L., Lune, H. (2012). Qualitative Research Methods for the Social Sciences. Hunter College. 8th Edition. ISBN-13: 9780205809387

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., Truffer, B. (2015). Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. *Environmental Innovation and Societal Transitions 16, pages 51-64*. https://doi.org/10.1016/j.eist.2015.07.003

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy 37*, pages 407-429. https://doi.org/10.1016/j.respol.2007.12.003

Cai, Y. (2014) What contextual factors shape "innovation in innovation"? – Integration of insights of the Triple Helix and the institutional logics perspective. *Social Science Information, 54(3),* pages 299-326. https://doi.org/10.1177/0539018415583527

Carayannis, E.G., Campbell, D.F. (2009). ''Mode 3' and 'Quadruple Helix': toward a 21st century fractal innovation ecosystem'. *International Journal of Technology Management, Vol. 46*, Nos. 3/4, pages 201-234. http://dx.doi.org/10.1504/IJTM.2009.023374

Carayannis, E.G., Campbell, D.F. (2010). Triple helix, Quadruple helix and Quintuple helix and how do Knowledge, Innovation and the Environment relate To Each other? A Proposed Framework for a Trans-disciplinary analysis of Sustainable development and Social Ecology. *International Journal of Social Ecology and Sustainable Development volume 1*, pages 41-69. http://dx.doi.org/10.4018/jsesd.2010010105

Carayannis, E.G., Thorsten, D., Barth, T., Campbell, D.F. (2012). The Quintuple Helix innovation model: global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship*. https://doi.org/10.1186/2192-5372-1-2

Carlsson, B. (2005). Internationalization of innovation systems: A survey of the literature. *Research Policy 35*, pages 56-67. https://doi.org/10.1016/j.respol.2005.08.003

Carlsson, B., Jacobsson, S., Holmén, M., Rickne, A. (2002). Innovation systems: analytical and methodological issues. *Research Policy 31*, pages 233-245. https://doi.org/10.1016/S0048-7333(01)00138-X

CEIC (2020). China Energy-initiated 10-Billion-Yuan New Energy Industry Fund Launched. https://www.ceic.com/gjnyjtwwEn/xwzx/202101/effdd2a5a7f24d37b9ef5bd71793132a.shtml (accessed on 16 July 2021).

Chan, L., Daim, T. (2012). Sectoral innovation system and technology policy development in China: Case of the transportation sector. *Journal of Technology Management in China, Vol. 7 No. 2*, pages 117-135. https://doi.org/10.1108/17468771211242827

Chang López, R. E. (2020). Universities as a fundamental component of innovation systems. *European Public & Social Innovation Review, 5(1)*, pages 1-9. https://www.pub.sinnergiak.org/esir/article/view/122

Chen, L. (2015). The Evolution of Intellectual Property Protection in China. *iBusiness 7*, pages 65-73. http://dx.doi.org/10.4236/ib.2015.71008

Chen, W., Li, Y. (2019). The internationalization process of Chinese research institutions since the reform and opening-up: Theory and practice. *Journal of Industry - University Collaboration, Vol. 1 No. 1*, pages. 2-16. https://doi.org/10.1108/JIUC-02-2019-001

Chesbrough, H. (2006). Open innovation: a new paradigm for understanding. *Open Innovation: Researching a New Paradigm. 1-12*. https://www.researchgate.net/publication/309563153_Open_innovation_a_new_paradigm_for_understanding

China Briefing (2019). Jiangsu Tax Cuts, Other Incentives for Private Sector Businesses. Retrieved from https://www.china-briefing.com/news/incentives-chinas-private-sector-jiangsu-tax-cuts-new-measures/

China Education Centre (2021). Education in China. https://www.chinaeducenter.com/en/cedu.php (acessed on 20 May 2021).

China Innovation Funding EU. (2021). Funding programmes. http://chinainnovationfunding.eu/chinese-innovation-funding-programmes/ (acessed on 18 July 2021).

China Internet Information Center (2002). Torch Program Contributes to Chinese Economy. http://www.china.org.cn/english/2002/Aug/39823.htm (accessed on 15 April 2021).

China Internet Information Center (2021). National Programs for Science and Technology. http://www.china.org.cn/english/features/China2004/107131.htm (accessed on 15 April 2021).

China Statistical Yearbook (2019). China Data Insights. Retrieved from https://cdi.global.cnki.net/Titles/SingleNJ?NJCode=N2019110002’

China Statistical Yearbook (2021). China Data Insights. Retrieved from https://cdi.global.cnki.net/Titles/SingleNJ?NJCode=N2019110002'

China Statistical Yearbook on Science and Technology (2021). China Data Insights. Retrieved from http://cdi.cnki.net/Titles/SingleNJ?NJCode=N2020030067

CNIPA (2013). Implementing Regulations of the Patent Law of the People's Republic of China. Retrieved from https://english.cnipa.gov.cn/art/2013/7/17/art_1349_81675.html

Cooke, P., Uranga, M.G., Etxebarria, G. (1997). Regional innovation systems: Institutional and organisational dimensions. *Research Policy 26*, pages 475-491. https://doi.org/10.1016/S0048-7333(97)00025-5

CSIS (2015). The East Is Green: China's Global Leadership in Renewable Energy. https://www.csis.org/east-green-chinas-global-leadership-renewable-energy (accessed on 16 July 2021).

Deloitte (2019). Rising Innovation in China [Brochure]. China Innovation Ecosystem. Development Report, Deloitte China. https://www2.deloitte.com/cn/en/pages/innovation/articles/china-innovation-ecosystem-development-report-20191.html

Dvorak, P., Saito, Y. (2018). Silicon Valley Powered American Tech Dominance - Now It Has a Challenger. *The Wall Street Journal*, April 12, 2018. https://www.wsj.com/articles/silicon-valley-long-dominated-startup-fundingnow-it-has-a-challenger-1523544804

Etzkowitz, H. (2003). Innovation in Innovation: The Triple Helix of University-Industry-Government Relations. *Social Science Information* 42, pages 293-337. https://doi.org/10.1177/05390184030423002

Etzkowitz, H., Leydesdorff , L. (2000). The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university–industry–government relations. *Research Policy 29, Issue 2*, February 2000, pages 109-123. https://doi.org/10.1016/S0048-7333(99)00055-4

European Commission (2011). Regional Innovation Monitor [Brochure]. Regional Innovation Report Berlin. Directorate D – Industrial Innovation and Mobility Industries. https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/report/innovation/regional-innovation-report-berlin

European Commission (2016). Regional Innovation Monitor Plus 2016 [Brochure]. Regional Innovation Report. Emilia-Romagna (Industry 4.0 and smart systems). https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/report/innovation/regional-innovation-report-emilia-romagna

European Commission. (2018). Knowledge for policy. https://knowledge4policy.ec.europa.eu/foresight/topic/expanding-influence-east-south/industry-science-innovation_en (accessed on 10 April 2021).

European Union (2021). EU-China Regional Innovation Joint Study [Brochure]. Regional Policy IUC Project. https://cdn.iuc-asia.eu/wp-content/uploads/2020/12/EU-China-Regional-Innovation-Joint-Study-2020.pdf

European Union Chamber of Commerce in China (2017). China Manufacturing 2025 - Putting Industrial Policy Ahead of Market Forces [Brochure]. https://www.europeanchamber.com.cn/en/press-releases/2532

Furman, J.L. , Porter, M.E., Stern, S. (2002). The Determinants of National Innovative Capacity. *Research Policy 31,* Issue 6, 2002, pages 899-933. ISSN 0048-7333. https://doi.org/10.1016/S0048-7333(01)00152-4

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems - Insights about dynamics and change from sociology and institutional theory. *Research Policy 33*, pages 897-920. https://doi.org/10.1016/j.respol.2004.01.015

Gilding, M., Brennecke, J., Bunton, V., Lusher, D., Molloy, P.L., Codoreanu, A. (2020). Network failure: Biotechnology firms, clusters and collaborations far from the world superclusters. *Research Policy, Volume 49, Issue 2*, 2020, 103902, ISSN 0048-7333. https://doi.org/10.1016/j.respol.2019.103902

GIZ (2021). Sino-German Energy Partnership. https://www.giz.de/en/worldwide/32698.html (acessed on 16 July 2021).

Global Innovation Policy Centre (2021). Measuring Momentum [Brochure]. GIPC International IP Index. First Edition, December 2012. https://www.theglobalipcenter.com/wp-content/uploads/2017/04/GIPC_Index_Report2012.pdf

Goess, S., De Jong, M., Ravesteijn, W. (2015). What makes renewable energy successful in China? The case of the Shandong province solar water heater innovation system. *Energy Policy 86*, pages 684-696. https://doi.org/10.1016/j.enpol.2015.08.018

Government of China (2005). Renewable Energy Law of the People's Republic of China. http://english.www.gov.cn/archive/laws_regulations/2014/08/23/content_281474983043598.htm (accessed on 16 July 2021).

He, F., Qin, D. (2006). China's Energy Strategy in the Twenty-first Century. *China & World Economy, Vol. 14*, pages 93-104, No.2. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.464.1292&rep=rep1&type=pdf

Hickey, K., Hart, N., Murrill, B. & Richards, K. (2020) Intellectual Property Violations and China: Legal Remedies. *Congressional Research Service*, CRS Report R46532, September 17, 2020. https://fas.org/sgp/crs/row/R46532.pdf

Hobday, M., Boddington, A., Grantham, A. (2012). Policies for design and policies for innovation: Contrasting perspectives and remaining challenges. *Technovation 32*, pages 272-281. https://doi.org/10.1016/j.technovation.2011.12.002

Hong Kong Trade Development Council (2021). Jiangsu: Market Profile. https://research.hktdc.com/en/data-and-profiles/mcpc/provinces/jiangsu (acessed on 20 July 2021).

Hotz-Hart, B. (2012). Innovation Switzerland: A Particular Kind of Excellence. *Innovation Policy and Governance in High-Tech Industries*, Chapter 6, pages 127- 154. https://doi.org/10.1007/978-3-642-12563-8_6

Information Office of the State Council of the People's Republic of China (2007). China's Energy Conditions and Policies [Brochure]. https://en.ndrc.gov.cn/policies/202105/P020210527780237298276.pdf

Innovation Policy Platform (2016). Overview of Inclusive Innovation Policies in the People's Republic of China [Brochure]. Chinese Academy of Science and Technology for Development, Beijing. https://www.innovationpolicyplatform.org/www.innovationpolicyplatform.org/system/files/imce/InclusiveInnovationPoliciesChina_FINAL/index.pdf

Jiangning Development Zone (2021). Profile and Strengths. http://en.jndz.cn/# (acessed on 06 July 2021).

Katz, S.J. (2006). Indicators for complex innovation systems. *Research Policy 35*, pages 893-909. https://doi.org/10.1016/j.respol.2006.03.007

KPMG (2020). Technology innovation hubs 2020 [Brochure]. What technology company executives and venture capitalists should understand about selecting and investing in global technology centers. https://home.kpmg/content/dam/kpmg/il/Publications/PDF/2020/03/tech-innovation-hubs_2020.pdf

Liu, C., Cai, Y. (2017). Triple Helix Model and Institutional Logics in Shenzhen Special Economic Zone. *Science and Public Policy, Volume 45, Issue 2*, April 2018, pages 221–231. http://dx.doi.org/10.1093/scipol/scx059

Liu, J., Li, J., Yao, X. (2019). The Economic Effects of the Development of the Renewable Energy Industry in China. *Energies 2019*, 12, 1808. https://doi.org/10.3390/en12091808

López, R. E. (2020). Universities as a fundamental component of innovation systems. *European Public & Social Innovation Review*, 5(1), 1-9. https://pub.sinnergiak.org/esir/article/view/122

Luengo-Valderrey, M-J., Pando-García, J., Periañez-Cañadillas, I., Cervera-Taulet, A. (2020). Analysis of the Impact of the Triple Helix on Sustainable Innovation Targets in Spanish *Technology Companies. Sustainability, 2020*; 12(8):3274. https://doi.org/10.3390/su12083274

Lundvall, B.Å., Johnson, B., Andersen, E.S., Dalum, B. (2002). National systems of production, innovation and competence building. *Research Policy 31*, pages 213-231. https://doi.org/10.1016/S0048-7333(01)00137-8

Malerba, F. (2002). Sectoral systems of innovation and production. *Research Policy 31*, pages 247-264. https://doi.org/10.1016/S0048-7333(01)00139-1

Manzoor, K., Sajid, S. (2018). Chinese Economy under Mao Zedong and Deng Xiaoping. *Journal of Political Studies, Vol. 25, Issue - 1*, 2018, 169:178. Retrieved from http://pu.edu.pk/images/journal/pols/pdf-files/11_25_1_18.pdf

Massey, J. (2006). "The Emperor Is Far Away: China's Enforcement of Intellectual Property Rights Protection, 1986-2006," *Chicago Journal of International Law: Vol. 7: No. 1*, Article 10. https://chicagounbound.uchicago.edu/cjil/vol7/iss1/10

Metcalfe, S., Ramlogan, R. (2008). Innovation systems and the competitive process in developing economies. *The Quarterly Review of Economics and Finance 48*, pages 433-446. https://doi.org/10.1016/j.qref.2006.12.021

Mierlo, B.V., Leeuwis, C., Smits, R., Woolthuis, R. K. (2010). Learning towards system innovation: Evaluating a systemic instrument. *Technological Forecasting & Social Change 77*, pages 318-334. https://doi.org/10.1016/j.techfore.2009.08.004

MIIT (2014). State Council. Ministry of Industry and Information Technology. http://english.www.gov.cn/state_council/2014/08/23/content_281474983035940.htm (acessed on 10 July 2021).

Ming, Z., Ximei, L., Yulong, L., Lilin, P. (2014). Review of renewable energy investment and financing in China: Status, mode, issues and countermeasures. *Renewable and Sustainable Energy Reviews 31*, pages 23-37. https://doi.org/10.1016/j.rser.2013.11.026

MOST (2021). Ministry of Science and Technology of the People's Republic of China. http://en.most.gov.cn/eng/index.htm (accessed on 10 April 2021).

Nanjing University (2021). Research at Nanjing University. https://www.nju.edu.cn/EN/6617/list.htm (acessed on 15 July 2021).

National Bureau of Statistics of China (2021). National annual data and regional annual data by province [Data set]. July 2021. https://data.stats.gov.cn/english/easyquery.htm?cn=E0103

National Government of People's Republic of China (2021). Special Report. The 11th Five-Year Plan. http://www.gov.cn/english/special/115y_index.htm

OECD (1997). National Innovation Systems. OECD Science, technology and innovation policy. https://www.oecd.org/science/inno/2101733.pdf (accessed on 11 February 2021).

OECD.Stat (2021). OECD Science, Technology and Industry Outlook: Comparative performance of national science and innovation systems. OECD Science, Technology and R&D Statistics (database). https://doi.org/10.1787/data-00669-en (accessed on 11 February 2021).

PHYS.ORG (2021). China's environmental data: The world's biggest polluter in numbers. https://phys.org/news/2021-04-china-environmental-world-biggest-polluter.html (acessed on July 19 2021).

Policy Watch (2021). The State Council. The People's Republic of China. Policies. Policy Watch. http://english.www.gov.cn/policies/policywatch (accessed on 10 April 2021).

Porter, M. E. (1990). The Competitive Advantage of Nations. *Harvard Business Review. International Business.* https://hbr.org/1990/03/the-competitive-advantage-of-nations

Property Rights Alliance (2020). International Property Rights Index. China. https://internationalpropertyrightsindex.org/country/china

Ranga, M., Etzkowitz, H. (2013). Triple Helix Systems: An Analytical Framework for Innovation Policy and Practice in the Knowledge Society. *Industry and Higher Education 27*, pages 237-262. https://doi.org/10.5367/ihe.2013.0165

Regione Emilia-Romagna (2021). https://www.regione.emilia-romagna.it/en (accessed on 11 February 2021).

Rivera León, L., Bergquist, K., Wunsch-Vincent, S., Xu, N., Fushimi, K., (2018). Economic Research Working Paper No. 44 [Brochure]. Measuring innovation in energy technologies: green patents as captured by WIPO's IPC green inventory. https://www.wipo.int/edocs/pubdocs/en/wipo_pub_econstat_wp_44.pdf

Roman, M., Varga, H., Cvijanovic, V., Reid, A. (2020). Quadruple Helix Models for Sustainable Regional Innovation: Engaging and Facilitating Civil Society Participation. *Economies Journal, Vol 8, issue 2.* https://doi.org/10.3390/economies8020048

Rubach, S., Hoholm, T., Håkansson, H. (2017). Innovation networks or innovation within networks. *IMP Journal, Vol. 11 No. 2*, pages 178-206. https://doi.org/10.1108/IMP-09-2015-0057

Science Business (2020). Green energy patents filed globally jump 28% in a year. https://sciencebusiness.net/news-byte/green-energy-patents-filed-globally-jump-28-year (acessed on 19 July 2021).

SDC (2020). The SDC International Report 2020 : Cooperating for Energy Transition. https://doi.org/10.7146/aul.395

Shen, W. (2016). The Role of Business in Driving and Shaping Renewable Energy Policies in China [Brochure]. Institute of Development Studies 2016. Evidence Report No 166. Rising Powers in International Development. https://www.researchgate.net/publication/292144496_The_Role_of_Business_in_Driving_and_Shaping_Renewable_Energy_Policies_in_China

Sheng, C. (2020). Not just the state: The role of entrepreneurs in China's energy transition. *Energy Research & Social Science, Volume 70*, December 2020. https://doi.org/10.1016/j.erss.2020.101814

Study in Jiangsu (2021). About Jiangsu. http://www.studyinjiangsu.com/About.html (acessed on 18 July 2021).

The Guardian (2007). China overtakes US as world's biggest CO2 emitter. https://www.theguardian.com/environment/2007/jun/19/china.usnews (acessed on 15 July 2021).

The State Council (2015). Premier urges use of Internet Plus to boost growth. http://english.www.gov.cn/premier/news/2015/06/25/content_281475134144826.htm (acessed on 10 July 2021).

The State Council of China (2021). Administrative Division. http://english.www.gov.cn/archive/china_abc/2014/08/27/content_281474983873401.htm (acessed on 06 July 2021).

Tödtling, F., Trippl, M. (2005). One size fits all?: Towards a differentiated regional innovation policy approach. *Research Policy 34*, pages 1203-1219. https://doi.org/10.1016/j.respol.2005.01.018

UNIDO (2015). UNIDO - China Energy Partnership. Inclusive and Sustainable Industrial Development [Brochure]. https://open.unido.org/api/documents/3470841/download/UNIDO-China%20Energy%20Partnership.pdf

US Department of Energy (2021). U.S.-China Energy Collaboration. Office of International Affairs. https://www.energy.gov/ia/initiatives/us-china-clean-energy-research-center-cerc (acessed on 16 July 2021).

US Energy Information Administration (2021). Country Profile. China. https://www.eia.gov/international/analysis/country/CHN (accessed on the 12 July 2021).

Wang, Q. (2010). Effective policies for renewable energy—the example of China's wind power—lessons for China's photovoltaic power. *Renewable and Sustainable Energy Reviews 14* (2010) 702–712. https://doi.org/10.1016/j.rser.2009.08.013

Watkins, A., Papaioannou, T., Mugwagwa, J., Kale, D. (2014). National innovation systems and the intermediary role of industry associations in building institutional capacities for innovation in developing countries: A critical review of the literature. *Research Policy 44*, pages 1407-1418. https://doi.org/10.1016/j.respol.2015.05.004

WIPO (2020). Patenting trends in renewable energy. Wipo Magazine. https://www.wipo.int/wipo_magazine/en/2020/01/article_0008.html (acessed on 15 July 2021).

WIPO (2021). Statistical Country Profiles. China. https://www.wipo.int/ipstats/en/statistics/country_profile/profile.jsp?code=CN (acessed on 12 July 2021).

Woolthuis, R. K., Lankhuizen, M., Gilsing, V. (2005). A system failure framework for innovation policy design. *Technovation 25*, pages 609-619. https://doi.org/10.1016/j.technovation.2003.11.002

World Bank (1994). World Development Report 1994 : Infrastructure for Development. New York: Oxford University Press. Retrieved from https://openknowledge.worldbank.org/handle/10986/5977

World Bank (2019). Innovative China : New Drivers of Growth [Brochure]. Development Research Center of the State Council, The People's Republic of China. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/32351

World Bank (2021). The World Bank in China. https://www.worldbank.org/en/country/china (accessed on 5 May 2021).

Ye, Y., De Moortel, K., Crispeels, T. (2020). Network dynamics of Chinese university knowledge transfer. *The Journal of Technology Transfer 45*, pages 1228–1254 (2020). https://doi.org/10.1007/s10961-019-09748-7

Zeng, M., Li, C. Zhou, L. (2013). Progress and prospective on the police system of renewable energy in China. *Renewable and Sustainable Energy Reviews, Volume 20*, April 2013, pages 36-44. https://doi.org/10.1016/j.rser.2012.11.048

Zhou, Y., Evans, M., Yu, S., Sun, X., Wang, J. (2020). Linkages between policy and business innovation in the development of China's energy performance contracting market. *Energy Policy, Volume 140*, 2020. 111208, ISSN 0301-4215. https://doi.org/10.1016/j.enpol.2019.111208