Taiwan Science and Technology Roadmap

(2019-2022)

Creating Taiwan's
Competitive Advantage
and
Maintaining Global Leading
Position in Innovation

(Short Version)

MOST 科技部
Ministry of Science and Technology

Taiwan
Science and Technology Roadmap

(2019-2022)

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Chapter 1. Introduction

The rapid progress in science and technology not only impacts the speed and direction of social change but also creates the capacity for economic growth. As we advance into the future, we must use science to meet the requirements for economic growth and social development, and continue to increase Taiwan's competitiveness in order to become one of the world's tech titans. To expand the value of science—that is, discovering new knowledge—to include promoting social and economic progress and increasing Taiwan's competitiveness, a comprehensive strategy for scientific and technological development is needed so as to meet future expectations through policy guidance and resource input. Only by keeping abreast of technological trends can we hold the key to future success. For this reason, the government acts in accordance with the Fundamental Science and Technology Act and regularly presents a statement describing the visions, strategies, and current status of scientific and technological development, focusing particularly on changes in international and domestic affairs as well as socioeconomic requirements, to raise Taiwan's standards in science and technology, drive economic development through innovation, boost national competitiveness, improve public wellbeing, and build a sustainable environment.

Previously, the White Paper on Science and Technology (2015-2018) was established on a framework of four dimensions: scientific research, environment, industry, and society. The scientific research dimension was aimed at expediting the translation of innovation outcomes by tapping into our strengths in science and technology, creating the value of excellence in scientific research, and building a sound environment for creation, innovation, and entrepreneurial efforts. The environment dimension was aimed at building a green energy environment by solidifying our foundation in the development of green energy technology, developing a safe, anti-disaster smart network, and implementing a mechanism for sustainable development. The industry dimension was aimed at promoting value-added science and technologies by devising plans to apply for intellectual property rights in science and technology, strengthening industries' power of innovation, and accelerating industrial smart upgrading. The society dimension was aimed at creating a happy, diverse society by building a safe environment, fortifying the social support system, and establishing a diverse, inclusive society.

The 10th National Science and Technology Conference in December 2016 drew upon three core values: basic environment, smart lifestyle, and economic development, branching into four topics: brilliance, low-carbon economy, well-being, and sustainability. Discussions on four key issues were conducted during the conference: How to revive economic dynamics through innovation; develop smart living technologies and industries; foster and recruit talent with diverse career paths; and enhance the innovation ecosystem for scientific research. Finally, the National Science and Technology Development Plan (2017-2020) was established following the conclusion drawn at the conference, suggestions afforded by experts and citizens, and consensus among members from different departments.

As we approach the two-year mark, the rapid evolution of science and technology has created new demands and challenges to Taiwan’s overall economy and society, such as economic and industrial changes driven by artificial intelligence (AI), the social impact of an aging population and declining birth rate, and the sustainable use of energy resources. Therefore, the direction of our national science and technology development must be reexamined. To solve these problems, we should uphold a “people-centered” core value in our strategies for national science and technology development and contemplate people’s actual needs in order to identify the appropriate solutions, use science to serve society, solve problems, and promote progress, and produce economic benefit from science.

A country’s true competitiveness does not depend on the area of its land and its natural resources, but rather it relies on creating unlimited socioeconomic value through innovative breakthroughs in science and technology. This is the true meaning behind the “Small Economy, Smart Strategy” principle. Because science is essentially aimed at discovering the unknown, the search for new knowledge is not limited by geographical borders or changes in time and space. It is filled with infinite imagination and possibility. When we choose to make our country prosper through science, it means that the country’s future development will be filled with endless possibilities.

Particularly when national resources are limited, a small country should persist in open innovation, encourage academic research institutes to collaborate and interact with outsiders, promote the exchange of scientific knowledge and brainstorming, and introduce outside resources to continuously bolster our national competitiveness.

In strengthening national competitiveness through science, we must begin from grounding our basic research by following a four-stage process (discovery, development, delivery, and commercialization, collectively called “3D1C”) to create opportunities for serving society with science and constructing a complete ecosystem of scientific research. First, the discovery stage involves encouraging the exploration of new knowledge to make scientific breakthroughs and discoveries. Second, the development stage aims to focus on promising areas of scientific research and develop new technologies. Third, the delivery stage serves to translate research findings into products for addressing existing problems and future challenges. Finally, the commercialization stage seeks to promote the commercialization of scientific research outcomes, meet economic and societal requirements, and create economic benefits from science (see Figure 1-1).

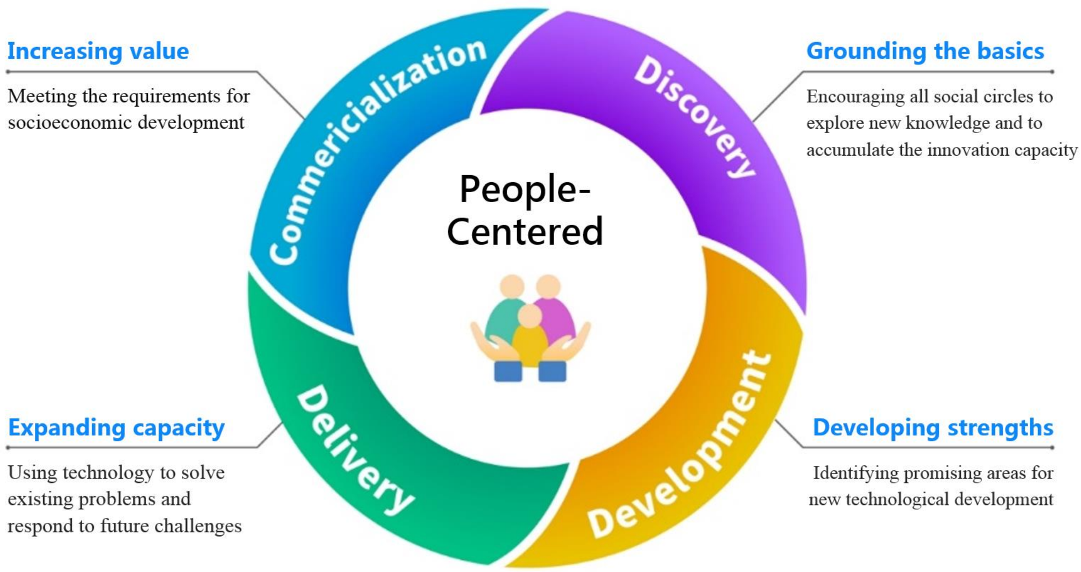

Figure 1-1. An ecosystem of scientific research

Innovation is the dynamic force driving a country’s economic growth. According to the World Economic Forum (WEF) 2018 Global Competitiveness Report, Taiwan demonstrated strong innovation capability, standing alongside Germany, the United States, and Switzerland as one of the world’s four Super Innovators. This achievement not only shows Taiwan’s exceptional competitive advantage but also lays the foundation for continuous economic growth and social advancement in the future. Therefore, the strategies for national science and technology development should tap into Taiwan’s strengths, innovation capacity, and potential, effectively utilize the country’s limited resources, and concentrate on key scientific and technological research and development to keep our position as the world’s leading innovator, thereby enhancing the overall economic development of Taiwan.

While developing new technologies to promote innovation, we will inevitably let our imaginations about the future of intelligence evermore, take advantage of the fourth industrial revolution to strengthen our industrial competitiveness, and create more diverse market demands to promote economic activities. For this reason, the Taiwan government should seize this opportunity and focus its attention on science and technology, such as developing AI technologies and applying them to economic activities, industrial operations, and people's everyday lives; strengthening cyber defense capabilities and cybercrime detection techniques; developing safe and efficient smart transportation systems; enforcing flexible laws and regulations for innovative systems to encourage creativity and innovation; perfecting mechanisms to train scientists and technologists; and accumulating technology-related human capital. All of these efforts can contribute to building a smart society.

Economic growth, increased living standards, and education have raised people's health awareness. However, people have extensive and diverse health-related needs, ranging from physiological health issues (e.g., public health, the prevention and treatment of epidemic and general diseases) to psychological health concepts (e.g., confidence and positivity). Therefore, technological elements are required to overcome the countless bottlenecks in a development process, such as making full use of new technologies to build long-term care systems and telemedicine networks; implementing precision medicine and preventive medicine to determine the cause of a disease and treat it accordingly; developing food safety technologies for stronger protection against food safety threats; and reinforcing public health systems to prevent epidemic and infectious disease outbreaks. All of these elements can facilitate the realization of a healthy society.

After the United Nations' (UN) announced its 2030 sustainable development goals (SDGs), the Environmental Protection Administration (EPA), Executive Yuan, launched a Voluntary National Review (VNR) on the SDGs on September 15, 2017, in an effort to continuously implement the sustainable development of Taiwan. In light of this, the national science and technology development strategies should focus on localizing sustainable development for Taiwan by promoting circular economy through comprehensive laws and regulations on resource recycling; increasing resilience in environmental governance to build a low-carbon living environment; developing diverse innovation capabilities and strengthening energy conservation initiatives by building smart grids for stable energy supply; establishing cross-border risk governance framework for greater capacity in early disaster warning; investing in marine technologies to sustain marine resources; and developing a sound regional innovation system to close the urban-rural gap.

After establishing the people-centered value of science and adhering to the "Small Economy, Smart Strategy" principle, we will compile a new White Paper on Science and Technology, drawing on the consensus of the previous National Science and Technology Conference. With the goal of continuing our legacy and opening up new possibilities in the future, the new white paper will provide a comprehensive overview of situations inside and outside of Taiwan, strategies adopted by other countries to develop their science and technology, inventory of problems and challenges existing in Taiwan, and future prospects of Taiwan's technological society. To integrate ministerial resources and effectively implement strategies for developing new-gen technologies, low carbon topics will be included as a direction of our sustainable development initiatives. We will also propose key points for Taiwan's future scientific research, improve Taiwan's scientific development policies, present the Taiwan Science and Technology Roadmap (2019-2022) to the people of Taiwan, continue to develop the nation's competitive advantage, and maintain Taiwan's position as the world's leading innovator. By following this Roadmap, we will make plans, take actions, analyze issues, and formulate strategies. This Roadmap is organized as follows. In Chapter 1, we briefly described the international trends, core values and policy visions, and how the Roadmap was established and the structure of the chapters. Chapter 2, "Brief Overview of International Situations and Current Situations in Taiwan," briefly reviews the scientific and technological development policies of benchmark countries and Taiwan and analyzes Taiwan's competitiveness in innovation. Chapter 3, "Major Issues, Challenges, and Response Strategies," examines current issues and proposes response strategies. Chapter 4, "Scientific Research and Technological Development," provides insight into the trends in global science and technology and an inventory of Taiwan's scientific research capacity to prepare for new technologies in the future. Chapter 5, "Small Economy, Smart Strategy," delineates the guidelines that Taiwan followed to build its competitiveness and continue to be the world's leading innovator.

Chapter 2. Brief Overview of International Situations and Current Situations in Taiwan

To ascertain the development trends of science and technology policies around the world, this Chapter first overviews the key science and technology policies and research and development (R&D) expenditures of major countries, providing a reference for the development of science and technology policies in Taiwan. Second, the current situation regarding Taiwan's innovation competitiveness is analyzed to offer insight into the country's innovation development capacity. Third, an inventory of major policy proposals presented by the Executive Yuan in recent years is conducted to grasp the focus of current science and technology policies.

1. The Focus of Global Policies on Science and Technology

According to the 2018 Organization for Economic Cooperation and Development (OECD) Science, Technology and Innovation Outlook report, governments around the world are attempting to shift the current direction of technological change toward economically, socially, and environmentally friendly technologies in accordance with the UN's SDGs, thereby encouraging private companies to follow suit by investing in technological innovations. The aforementioned change also gave rise to a new era, in which governments are enforcing task-oriented policies on scientific and technological innovation in hopes of promoting close cooperation between the business sector and the civil society and steering science and technology toward the wellbeing of society.

The purpose of governmental planning and implementation of science and technology policies is to promote the efficient use and integration of science and technology resources and innovate science and technology to meet Taiwan's developmental requirements with regards to medicine and health, information and food safety, environmental protection and energy, industrial productivity, etc. In the current era of globalization, science and technology strategies are no longer able to meet domestic demands; instead, these strategies should take into consideration the developmental requirements of industries, livelihood, and economy and address major issues of globalization, such as climate change and natural disasters, new viral and infectious diseases, and shortage of energy resources.

When development of science and technology innovation is headed toward the post Moore's law era, economic activities are also moving toward globalization, digitalization, and diversification, while various factors strengthen the role of science, technology and innovation policies in boosting a country's economic development. Nevertheless, science and technology policies cover a wide range of complex topics and requirements, including fundamental science and technological innovation, industrial competitiveness, and socioeconomic development, making strategic planning increasingly important. With the emergence of a large number of new technologies, developed countries are focusing their R&D strategies on basic research to deepen their R&D capacity, make new discoveries, and ultimately gain a prominent status in the newly discovered domain. Therefore, when planning science and technology strategies, developed countries take into account the balance between applied R&D and basic research. They use policy tools to maximize the benefit of resource allocation, with the hope of leveraging the outcomes of basic research to fortify their science, technology and innovation capability and promote national development.

Due to the economic recession and tightening of public budgets in developed countries, the people of these countries are hoping that the policies implemented by the government could yield immediate outcomes with social and economic benefits. In addition to continuously investing in infrastructures (e.g., talent cultivation, laws and regulations, and research facilities) for scientific and technological development, governments of various countries are slowly shifting their strategic focus to innovation and multidisciplinary cooperation with up/mid/downstream sectors. The goal is to promote industrial upgrade and transformation, and forge ties with international markets to boost economic growth, thereby placing innovation at the core of strategic planning. Innovation stems from the ideas of talented people, the accumulation of basic capacity, and execution capability. Therefore, countries are also actively recruiting, training, and retaining skilled workers as one of their main strategies for scientific and technological development.

(1) Scientific and Technological Development Visions of Different Countries

The goals, direction, and focus of scientific and technological development differ slightly for every country because of differences in R&D capacity, economic conditions, competitive advantage, natural resources, and industry characteristics, as well as the current state of a country. Despite these differences, the visions that countries have for their policies roughly include: Tackling future challenges, be the best in the world, promoting economic growth, and strengthening basic research to boost national development.

A. Tackling Future Challenges

In Asia Pacific, Japan and South Korea generally base their strategic planning on the technology foresight when setting goals for science and technology strategies. This is also why these countries place emphasis on scientific research strategies for tackling future challenges. Because Japan is situated in a disaster-prone area, the country attaches a great level of importance to scientific research on disaster prevention and emphasizes the use of scientific and technological innovation in strategic plans to perfect its disaster facilities. South Korea emphasizes promoting economic development and, hence, sets its strategies to boost industrial development and encourage innovative entrepreneurship. Singapore is committed to engineering and science and revolves the planning of its science and technology strategies around it, with the hope of becoming the first digital economy-based smart country. Mainland China is focused on stimulating the development of products and manufacturing industries through scientific and technological innovation, thereby laying for innovative entrepreneurship, talent development, and institutional reform.

B. Be the Best in the World

After Germany introduced the concept of Industry 4.0, the country has focused its high-tech strategies on the innovation of digital technologies and implemented revolutionary initiatives that facilitate the development of digital technologies, hoping to respond to societal and global challenges. Switzerland's science and technology strategies are focused on fostering talent and establishing stronger cooperation to retain the country's global leading status. Sweden's main strategy is aimed at perfecting the framework for innovation to stimulate the country's creativity and innovation capability as a whole. In sum, the policies implemented by these countries are all aimed at becoming the best in the world.

C. Promoting Economic Growth

Denmark classifies its science and technology strategies by application domain, placing emphasis on new materials, green solutions, and health care, in hopes of seizing growth opportunities from challenges. Finland adopts public wellbeing as the starting point to develop strategies for protecting the health and safety of its citizens. In Australia, science and technology strategies differ slightly from other countries in that they involve mainly strengthening the basic facilities and system framework for scientific research and are aimed at boosting economic development.

D. Strengthening Basic Research

Netherlands and the European Union (EU) used fundamental science as the cornerstone to address issues related to public wellbeing through open data, cooperation mechanisms, and tech talent development strategies to boost the country's overall development. However, in the Horizon Europe initiative, the EU emphasized using basic research to tackle future challenges and promote employment and industrial competitiveness, thereby addressing global issues. In contrast to the Horizon 2020 program, the Horizon Europe features a more open and far-reaching development strategy.

(2) Science and Technology Policies and Innovative Solutions of Different Countries

As evidenced by their major policy proposals and policy focus, various countries adopt similar policy directions, such as developing talents, laws and regulations, and innovation ecosystems; addressing socioeconomic problems, and tackling future challenges with the early layout. Because each country and economy are unique, they have slightly different visions, resulting in different development strategies, implementation measures, and area of focus. Plans for scientific and technological development in Taiwan are based on the Fundamental Science and Technology Act. Article 9 of this act states that the "government shall present a plan once every two years describing the visions, strategies, and current status of scientific and technological development," thus forming the basis of this Roadmap herein. In the following sections, we collected and organized the science and technology policies and innovative solutions of Japan, South Korea, Singapore, and EU states, all of which are countries that have fixed implementation schedule, long-term cycle, and regularly propose strategies for overall scientific and technological development.

A. Japan

Japan implements its science and technology policies in accordance with the Science and Technology Basic Law, which stipulates that "in order to achieve comprehensive and systematic promotion of policies to advance science and technology, the government must formulate a basic plan for advancing science and technology." The Science and Technology Basic Plan is a comprehensive policy for promoting scientific and technological R&D to advance Japan's science and technology. To effectively achieve the objective of the basic plan, the additional resolution of the Science and Technology Basic Law requires the basic plan to be based on a 10-year forward-looking and cover a five-year term. The 1st Science and Technology Basic Plan was implemented in July 1996. The 4th plan was supposed to be completed in March 2011; however, due to the 2011 Tōhoku earthquake and tsunami, the 4th plan was revised and reviewed, and disaster prevention strategies were incorporated, leading to the 5th Science and Technology Basic Plan (2016-2020).

Because of the rapid development of information and communication technologies (ICT), Japan's socioeconomic structure is entering a revolutionary era. To enhance the country's industrial competitiveness and overcome the increasingly complex problems (e.g., energy, declining birth rate, population aging, and natural disaster), thereby highlighting the necessity of promoting scientific and technological innovation, the 5th Science and Technology Basic Plan (2016-2020) was established to address the issues of the current economy and society. The plan contains four pillars, which are described as follows:

(A) Committing to creating new values for the development of future industries and social transformation so that Japan's science and technology can lead in the new era.

(B) Prioritizing to address and to face economic and social issues.

(C) Strengthening the basic research capability and reinforcing the fundamentals for science, technology, and innovation.

(D) Building a systemic virtuous cycle of human resources, knowledge, and funding for innovation.

The policy of the 5th Science and Technology Basic Plan is directed toward developing new technologies, equipping the environment, fostering talents, and realizing a super-smart society (Society 5.0). A super-smart society refers to a next generation society, in which humans advance into a new lifestyle after the transformation of a hunter-gatherer society, agricultural society, industrial society, and information society. Society is characterized by a high degree of merging between cyberspace and the real world and the capability to cross age, sex, region, and language barriers, provide necessary products and services to people who need them, simultaneously address economic and social issues, and ultimately seek to become a people-centered society.

To systematically realize a vision of super-smart society, Japan promotes revolutionary change by committing to the creation of future industries and social transformation. To strengthen the country's future competitiveness, Japan adopts a forward-looking perspective to ascertain domestic and international trends in scientific and technological development required to create future industries and enact social reform. Given the need for systematic implementation, sensor technology, robotics, nanotechnology, and other strengthens will be capitalized on to create fundamental technologies that further generate a broad range of business opportunities. The Internet of Things (IoT), big data analytics, AI, and information security technologies will be applied to promote R&D by solving multidisciplinary issues.

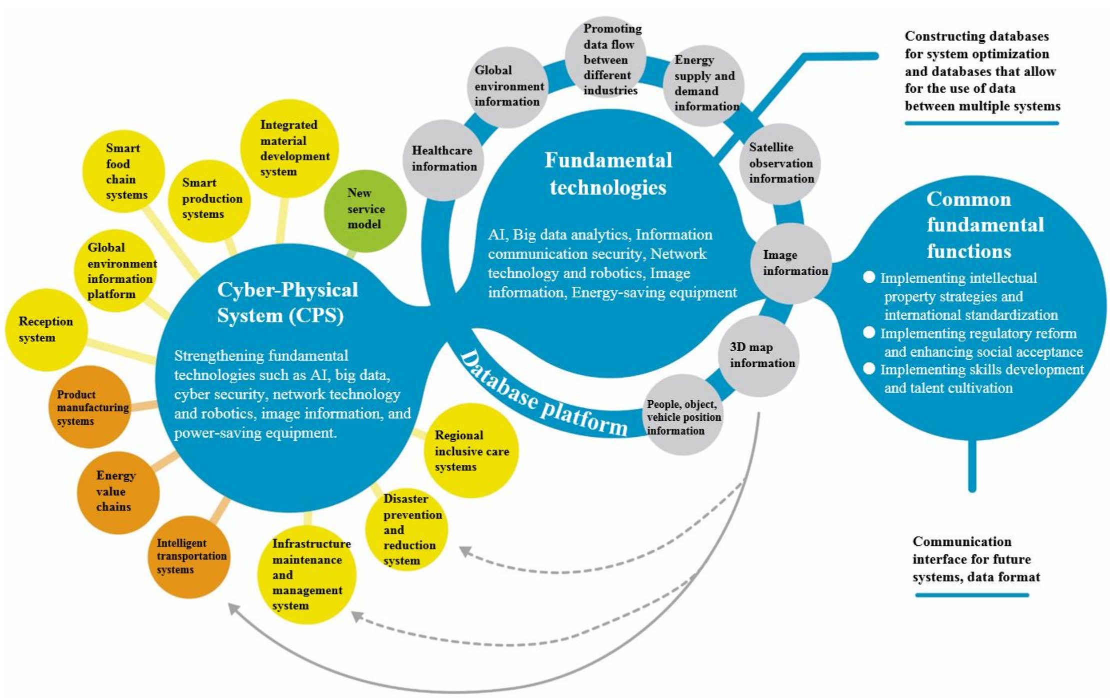

Figure 2-1. Japan's Society 5.0 platform

Data source: From Council for Science, Technology and Innovation Cabinet Office, Government of Japan; compiled by the Science & Technology Policy Research and Information Center (STPI) of Taiwan.

B. South Korea

South Korea's national science and technology development plan is based on the "Framework Act on Science and Technology," which was promulgated in 2001. In accordance with the provisions of the

Framework Act on Science and Technology, the Korean government shall formulate a Master Plan for Science and Technology every five years based on the nation's mid- and long-term development directions and objectives, and shall finalize the master plan after deliberation by the National Research Council of Science & Technology. The master plan is to be provided as reference for various ministerial departments to formulate scientific and technological development policies.

The 4th Master Plan for Science and Technology differs from the first three plans with regards to policy direction. First, the previous plans were focused on short-term outcomes and objectives, whereas the fourth plan emphasized the R&D of destructive innovation in order to inspire the passion to conduct free research and challenge R&D goals. Second, the previous plans were aimed at fostering professional talents, whereas the fourth plan was fostering new multidisciplinary talents to tackle the challenges of the fourth industrial revolution. Third, the fourth plan addresses the continuous shortening of future R&D periods, the integration of various science and technology domains in South Korea, and limited cooperation between the industrial, governmental, academic, and research sectors by increasing the openness of the country's R&D systems, actively building entrepreneurial and venture ecosystems, and encouraging citizens and local government to partake in technological innovation system. Fourth, although science, technology and innovation can drive socioeconomic development, it also affects employment patterns and weakens the dynamic of industrial growth. Therefore, the government should accelerate the fostering of innovative small and medium-sized enterprises (SMEs) and improve the employability of high-skilled workers. Fifth, South Korea has previously seen a rapid economic growth, which also negatively affected aspects relating to safety, health, environment, and employment. Therefore, the 4th Master Plan for Science and Technology not only seeks economic development but also proposes making contributions to the wellbeing of humans through scientific and technological R&D.

In response to future competitions and challenges in global science and technology, South Korea disclosed in its 4th Master Plan for Science and Technology how it envisions adopting scientific technologies to enhance people's quality of life and contribute to the development of human society. To achieve this vision, the Korean government analyzed its current situation and future visions, made adjustments according to the risks and issues of future societal development, and established four major strategic objectives, which comprise 19 key measures, as shown in Figure 2-2.

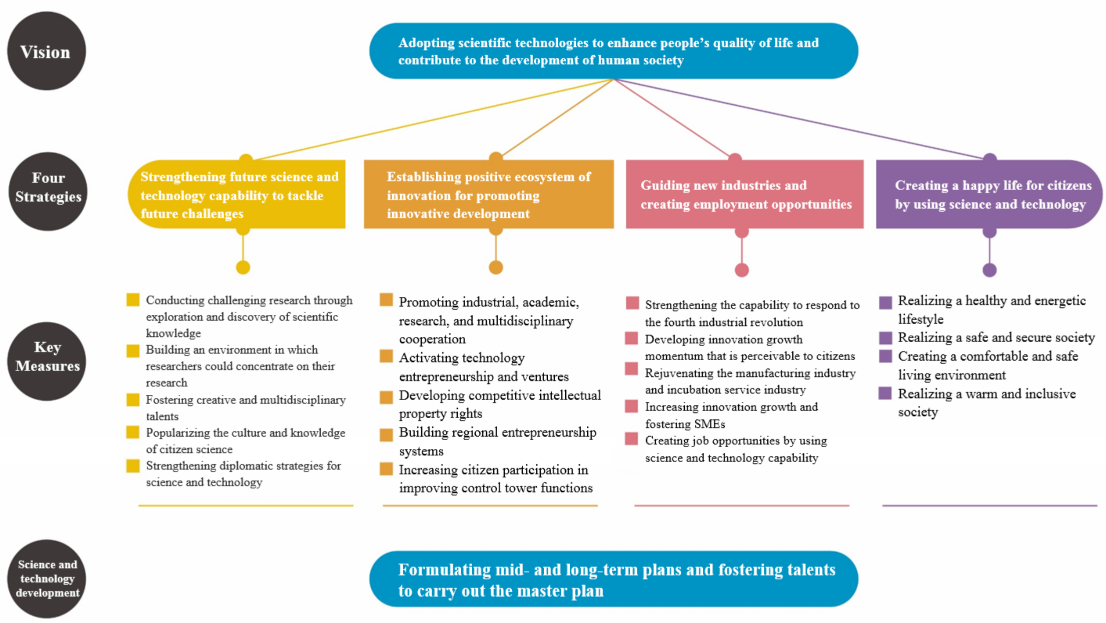

Figure 2-2. The policy framework of
South Korea's 4^{th} Master Plan for Science and Technology

Data source: the 4^{th} Master Plan for Science and Technology (2018-2022); compiled by the STPI.

C. Singapore

Singapore has been implementing the Research, Innovation and Enterprise (RIE) Plan since 1995 as its main policy for science and technology. RIE is the cornerstone for promoting the development of science, technology and innovation to develop Singapore into a knowledge-based innovation-driven country. A plan is proposed every five years and continuously revised to lay a robust foundation for the area of scientific research. The RIE plan is also a major science and technology policy designed to equip Singapore with the capability to research and develop cutting-edge technologies. Following the implementation of the past five RIE plans, Singapore has significantly enhanced the quality and quantity of its scientific research. Thanks to the RIE plans, academic and research institutes are able to continue to invest in building the infrastructure of their research and education, thereby building a pool of world-class researchers.

The 6th RIE plan (RIE2020) was proposed in 2016. The vision of this plan was to transform Singapore into a global research center and a smart nation. Under the RIE2020, four strategic domains of scientific research were proposed: advanced manufacturing and engineering, health and biomedical sciences, urban solutions and sustainability, and services and digital economy.

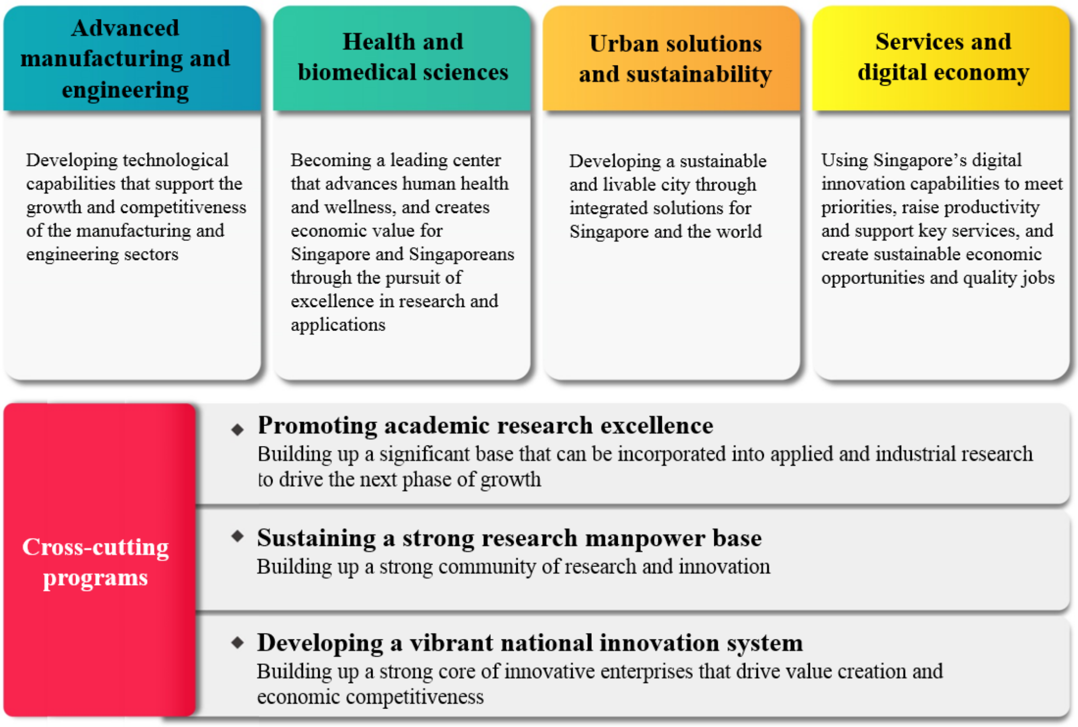

Figure 2-3. Policy objectives and framework of Singapore's RIE2020 Plan

Data source: Research, Innovation and Enterprise 2020 Plan; compiled by the STPI.

D. European Union

The European Union has implemented a series of Framework Programmes (FP), with the first FP launched in 1984. At the end of the 7th FP (2007-2013), the 8th FP was renamed the Horizon 2020. These programs all share the goal of enhancing the outcomes of frontier research and boosting the economic and social development of Europe. However, the scope of these programs is not limited to the innovation and development of science and technology; instead, it simultaneously drives a knowledge-based revolution to stay in line with the needs and values of the new era. In general, the EU hopes to promote and accelerate the development of global science, technology and innovation through the policy objectives of the FP and transnational cooperation mechanisms.

The implementation of Horizon 2020 helps Europe to realize a smart, sustainable, and inclusive economy. Horizon 2020 is aimed at ensuring that Europe produces world-class science, removes barriers to innovation, encourages cooperation between public and private sectors, and provides solutions to societal challenges. Horizon 2020 is divided into three pillars: Excellent Science, Industrial Leadership, and Societal Challenges.

In July 2018, the EU proposed a draft of the next program—Horizon Europe: The Next EU Research & Innovation Programme, (2021-2027). Similar to the ongoing Horizon 2020, Horizon Europe is also divided into three pillars: Open Science, Global Challenges and Industrial Competitiveness, and Open Innovation, which are described in the overall framework as shown in Figure 2-4.

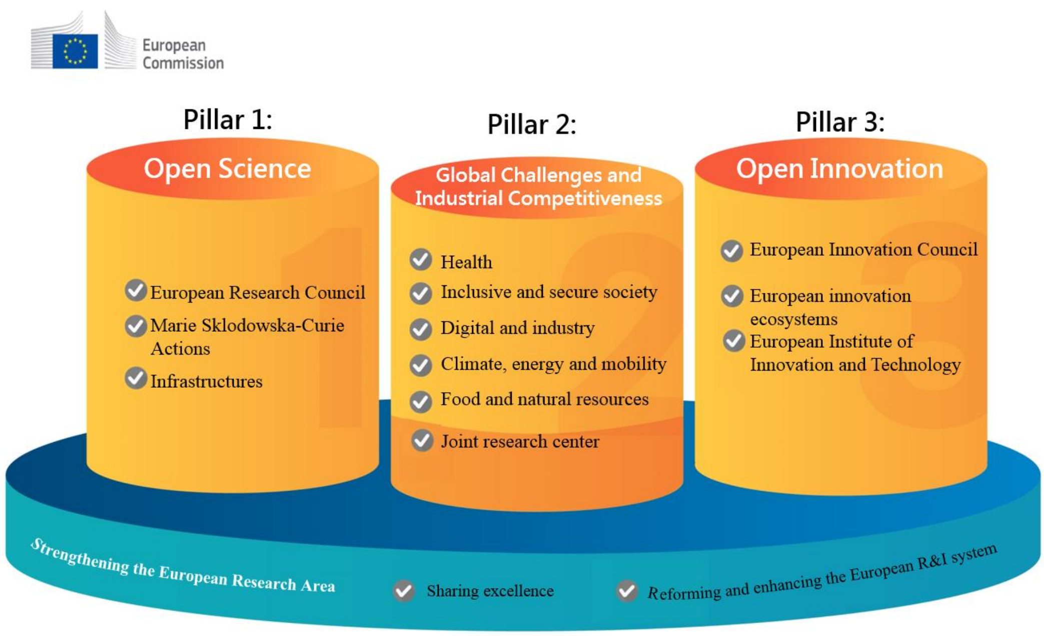

Figure 2-4. The policy framework of Horizon Europe (2021-2027)

Data source: Horizon Europe: The Next EU Research & Innovation Programme (2021-2027); compiled by the STPI.

(3) R&D Expenditures of Different Countries

Innovation stems from R&D; therefore, investment in R&D has gained global traction. The 2018 National Science Board (NSB) Science and Technology Indicators report showed that R&D expenditures worldwide totaled USD1.918 trillion, up 1.6 times from the USD722 billion in 2000. This increase indicates the high extent that investment in knowledge and technology is valued around the world.

Because different economic bodies have varying economies of scale and R&D focus, a country's innovation capacity is measured by R&D intensity[1]. The United States and Japan make considerable monetary investment in R&D initiatives; however, their R&D intensity in recent years has remained at roughly 2.7% and 3.3%, respectively. By contrast, the R&D intensity of China and South Korea has increased significantly, from 1.7% and 3.5% in 2010 to 2.1% and 4.2% in 2016, respectively. Although Taiwan saw only minimal increase in its R&D intensity (from 2.8% to 3.2%), a detailed analysis of its R&D funds shows that R&D expenditures in the past seven years were primarily spent by corporate organizations, averaging an annual growth rate of 7.33%[2]. Conversely, government-funded R&D expenditures as a percentage of nationwide R&D expenditures decreased from 32.7% in 1998 to 21.1% in 2015, which is below the average standard of a member country of the Organization for Economic Co-operation and Development (OECD). This shows that the Taiwanese government is lagging behind in terms of R&D expenditures.

Further breakdown of R&D expenditures by development focus shows that Taiwan is investing less in basic research, with only 8.7% of its R&D expenditures allocated to this area of focus in 2015, which is considerably lower than that of a number of countries such as the United States (16.8%) and Netherlands (27%). In other words, Taiwan's investment in basic research is decreasing, primarily because business enterprise, which are the chief contributors of R&D investment in Taiwan, are not focused on basic research. Compared with other countries, non-government sectors in Taiwan invested only 1.8% of their R&D input in basic research, which is substantially lower than that of the United States (12.1%), Netherlands (16.2%), and Israel (6.8%). Nevertheless, the basic R&D spending as a percentage of the government's total R&D spending is higher in Taiwan (34.7%) than in most of other countries. However, the Taiwanese government's total R&D spending is not increasing in proportional to the private sector's R&D spending. Therefore, Taiwan's investment in basic research still exhibits a decreasing trend[3].

1 R&D intensity refers to the ratio of a country's R&D expenses to its gross domestic product (GDP).

2 Data from Indicators of Science and Technology (2017) and calculated by the STPI.

3 The data published in the OECD Main Science and Technology Indicators show the percentage of different R&D activities (basic research, applied research, and experimental development) carried out in the government, business enterprise, higher education, and private non-profit sectors. These data do not present the numerical values of specific types of R&D invested by the various sectors. R&D funds may come from other sectors. The estimation of R&D investment data in this section was based on the source of fund and percentage of specific R&D activity carried out in different sectors.

The above results show that non-government sectors are not allocating enough resources to basic R&D investment, mainly because Taiwan's industries are characterized by mostly SMEs and original equipment manufacturers (OEMs). Before the successful transformation of Taiwan's current industrial structures, the Taiwanese government must provide increased support for basic research in order to compensate for the lack of investment made by the private sector.

(4) Summary

This section reveals that different countries' policies for scientific and technological development revolve around the three axes of brilliance, well-being, and sustainability, which are the same topics discussed in Taiwan's 10th National Science and Technology Conference[4]. The R&D competition among various countries has driven the explosive growth of big data analytic, IoT, AI, and other emerging technologies, establishing a global trend in digital innovation and development, in which basic research is a significant contributor. Climate change, energy resources shortage, change in population structure, among other global issues are also prompting governments worldwide to rethink their roles and positions in science and technology policies. Planning national strategies for scientific and technological development in the direction of global major issues and future challenges has also become a mainstream in global policy planning. Meanwhile, governments must design, plan, and formulate policies more openly and with greater agility so as to meet domestic demands and solve future problems.

2. Analysis of Taiwan's Current Innovation Competitiveness

In recent years, Taiwan has performed favorably in national competitiveness evaluations and international evaluations relating to brilliance, well-being and sustainability. This achievement shows that under the fierce global competition, Taiwan remains capable and competitive in innovative development. According to the 2018 WEF Global Competitiveness Report, Taiwan scored 79.3 in competitiveness, ranking 13th out of 140 countries and 4th in Asia, alongside Singapore, Japan, and Hong Kong.

[4] The low-carbon economy and sustainability topics presented in Taiwan's 10th National Science and Technology Conference cover issues on green technology, circular economy, and resilient city, which are consistent with the sustainability topic included in other countries' policies for scientific and technological development.

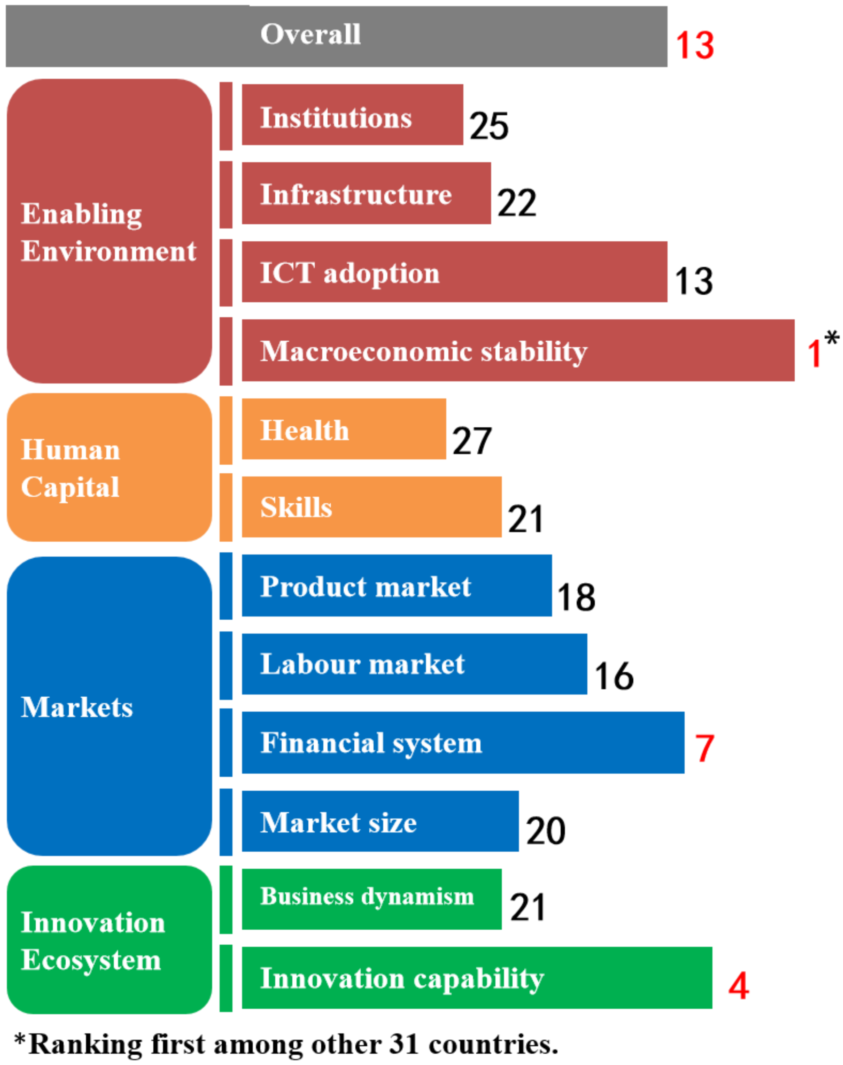

Figure 2-5. Taiwan's ranking across the 12 pillars in the 2018 WEF Global Competitiveness Report[5]

Figure 2-5 shows Taiwan's overall ranking and its ranking across the 12 pillars. Out of the 140 countries, Taiwan performed fairly well across the various pillars. Specifically, Taiwan obtained a perfect score of 100 on the pillar Macroeconomic Stability, ranking first among other 31 countries. Taiwan ranked 7th in Financial System and 4th in the Innovation Capability pillar of the Innovation Ecosystem index. The WEF rated Taiwan, Germany, United States, and Switzerland as "Super Innovators." These accomplishments show that the country's improved innovation capability is a testament to the effectiveness of Taiwan's recent policies for encouraging innovation, optimizing startup business

[5] National Development Council, 2018, Taiwan's ranking in the Global Competitiveness Index 4.0 2018 Rankings.

investment environment, and promoting key industrial innovation plans. Moreover, Taiwan ranked 17th out of the 63 economies rated in the 2018 World Competitiveness Yearbook published by the International Institute for Management Development (IMD). According to the National Development Council (2018), Taiwan ranked in the top 10 across 4 indicators, namely Price (9th) under Economic Performance, Tax Policy (4th) under Government Efficiency, Management Practices (9th) under Business Efficiency, and Scientific Infrastructure (10th) under Infrastructure. In particular, Taiwan performed fairly well in the total number of R&D personnel (1st), ratio of business R&D expenditure to GDP (4th), ratio of total R&D expenditure to GDP (5th), ratio of added value of knowledge- and technology-intensive industries to GDP (5th), number of patents in force (5th), and number of research personnel in the R&D facilities (8th). These rankings reveal Taiwan's strong and solid base in scientific and technological R&D.

Regarding Taiwan's ranking in smart and digital competitiveness, the 2018 IMD World Digital Competitiveness Ranking report served to assess the extent to which a country adopts and explores digital technologies leading to transformation in government practices, business models and society in general. Taiwan was ranked 16th out of 63 economies and 5th in the Asia Pacific area. Taiwan ranked in the world's top three across five criteria and listed these as its strengths. These criteria included Educational Assessment PISA - Math (3rd) and Total R&D Personnel Per Capita (1st) under the Knowledge factor; IT & Media Stock Market Capitalization (2nd), Mobile Broadband Subscribers (2nd), and High-Tech Exports (3rd) under the Technology factor. These rankings also show Taiwan's weakness in attracting foreign high-tech talents to work in the country, and this weakness should be addressed in Taiwan's policies in the future.

Regarding international ratings related to sustainable development, the Dow Jones Sustainability Index (DJSI) is the most significant corporate sustainability rating index for tracking the corporate social responsibility (CSR) of international companies. DJSI also became a reference index evaluating the investment performance of various countries. According to the 2018 DJSI World Index, the number of enterprises in Asian countries to be included in the DJSI World Index was the highest for Japan (n=34), followed by South Korea (n=20), and then Taiwan (n=12). Twenty Taiwanese enterprises were included in the DJSI Emerging Markets Index, showing the commitment and level of importance that Taiwanese enterprises attach to CSR and sustainable development.

Regarding international ratings for health and medicine, Taiwan's medical techniques and health care systems have gained international traction. The 2018 Nobel prize winner in economies, Paul Krugman, praised Taiwan's health care system in a column called "Pride, Prejudice, Insurance." Taiwan is equipped with advanced medical environment and high-quality services. In 2012, the documentary "Asia New Vision: Taiwan's Medical Miracle" from National Geographic Channel spoke highly of Taiwan's medical techniques and service capabilities. In 2018, the Bloomberg analysis revealed the world-leading status of Taiwan's medical techniques, with Health Care Efficiency ranking 9th in the world.

According to world competitiveness international ratings in various domains, Taiwan holds competitive advantage in scientific research capacity, scientific infrastructure, innovation ecosystems, and scientific research talents. The country's digital competitiveness in brilliance, well-being and sustainability, corporate commitment to sustainable development, and health care efficiency and standards have also garnered international attention, suggesting that Taiwan has the potential and strengths in technological innovation. However, Taiwan still needs to strengthen its efforts to attracting foreign high-tech talents, developing corporate innovation and digital application capabilities, building ICT infrastructures for corporate development, and increasing the impact factor of patents and academic papers. In future, we should build an innovation-based environment, maximize the strengths of scientific research talents, and strengthen competitiveness in niche fields to bolster the innovation competitiveness of Taiwan.

3. Executive Yuan's Major Policy Plans

In this section, we provide an inventory of the Executive Yuan's key policy plans, including the National Science and Technology Development Plan (2017-2020), the 5+2 industrial innovation plan, etc. We then chronologically describe the implementation focus of each plan according to the schedule of each plan to provide a basis for the strategic planning of the current Taiwan Science and Technology Roadmap (2019-2022).

(1) The National Science and Technology Development Plan (2017-2020)

The 2017 National science and Technology Development Plan proposes four strategic objectives and visions. The objectives were to revive economic dynamics through innovation; to develop robust smart living technologies and industries; to foster and recruit talent with diverse career paths; and to enhance the innovation ecosystem for scientific research. In strengthening scientific research outcomes to promote industrial development, we must revive the digital economy and talents in industrial science and technology and reinforce practical training mechanisms to enhance the economic development of innovation industries. The strategies included creating development models of digital economy for industrial innovation; strengthening the translation of scientific achievements into industrial innovation and development; building a robust regional innovation system to sustain the growth dynamics of industrial clusters; and creating a friendly environment and development mechanism for innovation and start-ups. By cooperating with central and local agencies, we strive to establish the economic development of regional industries, strengthen industry-government-academia subsidy mechanisms and links, drive the development of the 5+2 industrial innovation, and construct a R&D platform so as to facilitate industry upgrading and creation of a new generation industrial site, thereby increasing employment opportunities and the probability of success in innovative startups.

(2) The 5+2 Industrial Innovation Plan

The Taiwanese government has been implementing the 5+2 Industrial Innovation Plan to promote industrial development and innovation targeting industrial requirements to realize economic growth. The 5+2 Industrial Innovation Plan is focused on Smart Machinery, Asia-Silicon Valley, Green Energy, Biomedical, Defense, New Agriculture, and Circular Economy.

A. Smart Machinery Industry Promotion Program

The vision of the Smart Machinery Industry Promotion Program is raising productivity through innovative industrial production processes to industrialize smart machineries and integrate smart machineries in industries. Three strategies are adopted to promote the smart machinery industries: (A) Joining local industries together: To create a city of smart machinery and integrate the capacities of industries, academia, and research institutes; recruit and train talented professionals and R&D personnel from various regions through collaborations between the government and industries, academia, and research institutes; and find sites for the development of smart machinery industries from Taiwan’s urban development plans to showcase related products (e.g., smart vehicles and unmanned vehicles). (B) Building links to the future: Systemizing solutions by increasing the depth of technologies to develop autonomous technologies and components for smart machineries;

proposing total solutions for aviation, semiconductor, smart transport, green vehicle, and energy industries; integrating the systems of various industries and introducing them to international communities. (C) Connecting to the World: Cooperating with international companies to sell Taiwanese products abroad; promoting smart machinery industry exchange between Taiwan and other countries, that is, Europe, the United States, and Japan after the aforementioned industrial systems are integrated and introduced to the international community; and exporting and expanding smart machinery products to international markets.

B. Asia Silicon Valley Development Plan

Approved in September 8, 2016 by the Executive Yuan, the Asia Silicon Valley Development Plan was established to construct a R&D-based ecosystem for innovation activities and entrepreneurial efforts. The program is focused on “promoting the innovative R&D of IoT industries” and “strengthening ecosystems for innovation activities and entrepreneurial efforts.” By joining local industries together, connecting to the world, building links to the future, the plan capitalizes on central and local cooperation to promote cross-domain innovation and cross-regional integration. The following strategies are adopted in the plan: (A) Building robust ecosystems for innovation activities and entrepreneurial efforts to realize the spirit of the Silicon Valley and forge stronger ties with Asia. Measures include attracting talents, providing comprehensive financial assistance, perfecting laws and regulations on innovation, and providing innovation sites. (B) Linking to the R&D capacity of Silicon Valley and other international entities to build innovation R&D base. Measures include establishing links to Silicon Valley and other innovation clusters, introducing innovation capacity, and seizing next-gen IoT opportunities. (C) Integrating software and hardware applications to increase soft power and build a complete IoT value chain. Measures include investing additional innovation capacity and academic resources to improve software power, industrialize the IoT R&D outcomes of academic research institutes, and build IoT ecosystems. (D) Integrating physical and virtual clusters to provide diversified demonstration sites for innovation activities, entrepreneurial efforts, and smart product development. Measures include building environments for verification testing, promoting smart application service demonstration plans, implementing the smart transformation of science parks, and initiating diverse demonstration plans.

C. Promotion Program for Green Energy Technology Industries

The vision of promoting green energy industries in Taiwan is promoting green energy, industrial development, and technological innovation, with a focus on “energy harvesting, energy storage, energy conservation, and smart system integration” to help the government to implement energy transformation and generate 20% renewable energy by 2025. By promoting green energy industries, the program hopes to drive energy transformation and economic development in Taiwan. Regarding implementation strategies, energy harvesting is achieved by developing photovoltaic technology, offshore wind power, biofuel, geothermal energy, and marine energy; leveraging the characteristics of local industries; and strengthening the global competitiveness of local industries. Energy storage is achieved by promoting the verification of regional energy storage equipment demonstrations; developing household, business, and electric grid energy storage systems; refining key materials and control management models; supporting electric power transmission supply systems; and increasing the reliability of power supply. Energy conservation is achieved by developing energy-saving technologies and green construction materials, and promoting the retrofitting of energy-saving equipment, energy conservation laws and regulations, energy-saving services, and energy conservation education to enhance energy efficiency. Smart system integration is achieved by promoting the integration of industries’ cross-domain systems, building a smart electric grid, incorporating the management of IoT, big data, ICT modules and electricity generation, developing energy service industries and a circular economy advocating carbon reduction and use of clean coals. The program also aims to realize the construction of the Shalun Smart Green Energy Science City, which will serve as the display window for showcasing Taiwan’s green energy technologies to the world and a bridge connecting Taiwanese industries to the international market. Through the implementation of this program, we hope to realize energy transformation and sustainable value while ensuring that energy is used safely, green economy is developed, environmental sustainability is promoted, and social fairness is enhanced.

D. Biomedical Industry Innovation Program

In November 10, 2016, the government proposed the Biomedical Industry Innovation Program. The core concept of this program is “Building links to the future, connecting to the world, joining local industries together." The vision of this program is transforming Taiwan into Asia Pacific's biomedical R&D hub. The objective is to create a complete ecosystem in response to the global aging population trend, integrate local innovation clusters, gather international market resources, and promote characteristic industries, thereby promoting the biotechnology industries to boost Taiwan's economy and improve the health and welfare of Taiwanese citizens.

Strategies include the following: (A) Creating a complete ecosystem by strengthening six dimensions of fund, talent, topic selection, intellectual property, laws, and resources and improving innovation performance. (B) Integrating local innovation clusters by integrating links to the industrial, academic, and research sectors, creating a complete ecosystem, and promoting the development of new drug and medical instruments. (C) Connecting to the international market resources by extending global presence to increase the competitiveness of medical centers and turn Taiwan into Asia Pacific's biomedical R&D hub and by developing southward to help hospitals or manufacturers to negotiate better conditions with Southeast Asian governments, encourage hospitals or manufacturers to expand their Southeast Asian markets, and build training centers in Taiwan to recruit Southeast Asian talents. (D) Promoting characteristic industries by developing precision medicine, building world-class clinic clusters, and increasing the capacity of health and well-being industries.

E. New Agricultural Innovation Promotion Program

The Executive Yuan Council of Agriculture adheres to the President's policy blueprint and follows the four principles of new agriculture promotion (innovation, employment, distribution, and sustainability), with the hope of linking local industries to secure stable source of income for farmers and ensure quality consistency while maintaining the total output of farmlands so as to enhance food safety and sustain the operation of the agricultural industry. Three strategies are simultaneously proposed to implement the program: Establishing a new paradigm for the agricultural industry (implementing a green environmental payment program, stabilizing agricultural incomes for farmers, enhancing the competitiveness of livestock and poultry in Taiwan, popularizing eco-friendly farming practices, promoting the sustainable use of agricultural resources, and making aggressive use of technological innovations); constructing systems to ensure agricultural safety (enhancing food safety and ensuring the safety of agricultural products); and improving agricultural marketing capabilities (increasing and diversifying both domestic and export sales channels for agricultural goods and raising the value-added component of agricultural end products). The end goal is to increase the area of farmlands eligible for the green payment program by 2020. To enhance food safety and ensure the safety of agricultural products, we must first control the total farmland output and raise food self-sufficiency rate, and then implement source management to ensure no pesticide and heavy metal pollution so that farm products can be sold domestically and abroad via diverse sales channels to identify new markets (Association of Southeast Asian Nations, South Asia, New Zealand, and Australia) and infuse new goals and visions in the new agriculture program: sustainable agriculture, environment protection, consumer safety, and farming modernization.

F. Circular Economy Promotion Plan

On December 20, 2018, the Executive Yuan approved the Circular Economy Promotion Plan. The plan involves embedding circular economy concepts and innovative sustainability thinking into the industry’s economic activities, implementing them in production, consumption, recycling, and reuse processes to transform industries from a linear economy into a circular economy, thereby creating new momentum. The main thrust of the plan is to turn the circular economy into an industry while applying a more circular approach to industrial processes. In other words, key industries (e.g., metal, fossil, and other material industries) are assisted to research and develop innovative material technologies and increase the value of renewable resources. Concurrently, the research capacity of the industrial, public, and academic sectors is leveraged to plan and implement a new circular economy demonstration park. Specific approaches and strategies are as follows: (A) Promoting circular technologies and materials innovation and establishing R&D centers; (B) constructing a new circular economy demonstration park; (C) encouraging green consumption; and (D) integrating resources and promoting industrial symbiosis.

(3) Forward-Looking Infrastructure Development Program

This program was approved in 2017. The vision of this program is focused on prospects, sustainability, and regional balance. The objectives of this program are to construct (A) safe railway infrastructure for fast transportation, (B) water environments to build resilience against climate change, (C) green energy infrastructure to ensure environmental sustainability, (D) digital infrastructure to create a smart nation, and (E) urban and rural infrastructures to balance regional development. First, regarding railway infrastructure, the government hopes to develop a wide range of seamless, high-quality transportation services that can boost the tourism industry. Second, regarding water infrastructure, the government hopes to build a high-quality water environment that ensures stable supply of clean water. Third, regarding green energy infrastructure, the government hopes to strengthen the infrastructures for green energy development and encourage private and public enterprises to invest in renewable energy. Fourth, regarding digital infrastructure, the government hopes to develop an "ultra-wideband network society" in which digital services, information security, and other infrastructures are promoted to transform Taiwan into "a digital country and an innovative economy." Fifth, regarding urban rural infrastructures, the government hopes to actively develop rural infrastructures to bridge the urban-rural gap and improve the quality of life of rural residents.

(4) AI-Related Plans

A. Strategies for AI Scientific Research

In 2017, the government formulated a strategy to develop infrastructures for AI scientific research. In the "small economy, smart strategy" principle, the government sets to launch a series of AI development to bolster the country's competitiveness. Upholding a people-centered core value, the strategy serves to establish ecosystems for AI innovation and apply AI technologies to create smart lifestyles for people of the new generation, thereby helping Taiwan to ascend to prominence in the value chain of the international AI industry.

The objective of the strategy is to develop an AI innovation ecosystem composed of talent, technology, site, and industry by using the strengths of Taiwan's world-leading ICT industries as the basis and five key facets, which are described below: (A) R&D services: An AI server will be developed to provide a large-scale, shared-use, high-speed computing environment with stronger in-depth learning and big data analytic technologies. (B) Value-added innovation: AI innovation research centers will be established over a period of five years to develop AI technologies, train AI specialists, assemble a multidisciplinary team of technologists, and increase international competitiveness. (C) Creativity and practice: An AI Robot Makerspace is to be established over a four-year period to research and develop robotics, provide a creative platform for people to gain hands-on experience, implement a mode of sustainable operation, and boost the development of smart robotic industries in Taiwan. (D) Industrial pilot program: A four-year AI Semiconductor Moonshot Program is underway to reinforce the R&D of AI-powered semiconductor manufacturing process and chip system, develop next-gen memory designs, develop cognitive computing and AI chips, develop unmanned vehicle and augmented reality (AR)/virtual reality (VR) applications, and perfect the IoT system and security. (E) Social participation: The Formosa Grand Challenge technology competitions will be organized to raise awareness on AI, encourage people to participate in challenge competitions, inspire innovative and creative solutions, and expand the capacity of related industries in Taiwan.

B. AI Taiwan Action Plan

The AI Taiwan Action Plan is established on the framework of the Digital Nation and Innovative Economic Development Program (DIGI+) and the consensus and conclusion of the Executive Yuan's "Strategic Review Board Meeting for the Smart System and Chip Industry" to realize the vision of "prioritizing innovation experiences, developing software and hardware in tandem, thereby injecting greater momentum into Taiwan's industries." The action plan comprises five major components: (A) Fostering AI talent: This component consists of talent cultivation, talent retention, and talent recruitment; cultivation, training, and convergence processes are used to cultivate thousands of smart-tech elites, train tens of thousands of smart application pioneers, and attract AI technicians from around the world. (B) Promoting Taiwan's lead role in AI: This component is focused on promoting niche-based research topics to be implemented by domestic and foreign project teams, which are carefully selected through an open competition and recruitment process; Taiwan's international presence is extended to attract global elites, integrate forward-looking research, training programs, and scientific research projects, and construct a mechanism that facilitates information sharing, horizontal communication, and vertical integration, thereby building an AI forward-looking research network for Taiwan. (C) Building Taiwan into an AI innovation hub: This component aims to support hundreds of AI startups, encourage new AI startups to join the supply chain of international industries, simultaneously motivate international flagship companies to set up R&D base in Taiwan, and use this opportunity to develop world-class AI innovation clusters. (D) Relaxing laws and opening test grounds: This component aims to open testing grounds for AI application verification, develops an open data ecosystem, and concurrently accelerate the relaxation or adjustment of related laws. (E) Assisting with industries' AI transformation: An AI innovation matching platform will be implemented to realize benefits for industries. AI talents will be matched to the innovation needs of the 5+2 industries to build a complete environment that facilitates industries' AI transformation, promote AI innovation transformation among SMEs, and help industries to solve problems.

(5) Digital Nation and Innovative Economic Development Program (2017-2025)

In 2017, the Executive Yuan initiated the DIGI+ program (2017-2025). With "digital nation and smart island" as the general policy direction and the vision of "developing a dynamic network society, promoting high-value innovation economy, and constructing a wealthy digital country," the DIGI+ program is intended to build a well-equipped digital environment for the innovation of Taiwan's 5+2 industries, facilitate the rigorous development of domestic industrial innovations, and accelerate the development of Taiwan into a "smart nation." Through the DIGI+ program, the government hopes to achieve the following by 2025: rapidly expand Taiwan's digital economy; increase the penetration rate for digital lifestyle services; secure citizens' basic rights to accessing broadband internet; and improve Taiwan's global ranking for network readiness. DIGI+ is a 9-year program designed to promote broadband infrastructure and build infrastructures that are conducive to industrial innovations. The program features six major components: Digital innovation infrastructure, promotion of the digital economy, network society and digital government, intelligent cities and regional innovation, fostering of interdisciplinary digital talents, and R&D of advanced digital technologies, to realize civic participation and balanced regional development, create a sound digital nation innovation ecosystem, protect the rights of digital users, and develop a wealthy digital country that engages in active innovation.

(6) National Cyber Security Program of Taiwan (2017 to 2020)

The National Cyber Security Program of Taiwan (2017 to 2020) is based on the vision of “building Taiwan as a safe and reliable digital country” and the current situation regarding information security risks. The objectives of the program are constructing a national cybersecurity defense system, upgrading the overall cybersecurity protection mechanism, and enhancing the development of self-managed cybersecurity industries. Previously, cybersecurity protection mechanisms were generally used in government agencies, while private companies independently managed their own cybersecurity matters. To enhance local cybersecurity protection networks, six municipalities are used as the bridge connecting neighboring cities and counties to national cybersecurity networks. Subsequently, four strategies are adopted:

“complete the cyber security infrastructure”, “construct a national united defense term in cyber security”, “increase the self-development energy of cyber security”, and “nurture excellent talents in the field of cyber security” to gradually implement cybersecurity protection measures to perfect Taiwan’s cybersecurity legal governance systems, and elevate the country’s overall cybersecurity protection capacity. This program is expected to promote the development of cybersecurity industries in Taiwan through national defense systems, and foster cybersecurity experts with greater self-management capability so that the central and local governments are equipped with more comprehensive cybersecurity protection mechanisms.

An overview of science and technology policies in Taiwan and other countries shows that all of the policies were established to meet societal needs; research and develop digital and automated smart technologies; create a safe, happy, and healthy society; and develop sustainable economy, society, and environment. For this reason, the current Taiwan Science and Technology Roadmap (2019-2022) will uphold a People-Centered core value and provide the objectives and strategies of Taiwan’s scientific and technological development to create competitive advantages so that Taiwan can keep its position as the world’s leading innovator.

Chapter 3. Major Issues, Challenges, and Response Strategies

To tackle the challenges facing a country's society, the direction of new national scientific and technological development must be based on people's needs to identify the appropriate solutions, uphold a People-Centered core value, and use science to promote economic development and to solve societal problems.

In this chapter, we first identify major issues, review the implementation status of policies related to the major issues, summarize the conclusion of major conferences, collate the advices of business groups, opinions of expert scholars, and public sentiment, and formulate response strategies and measures.

Current societal issues concerning science and technology policies that are of concern to the people of Taiwan can be divided into "health and social security," "industry and economy," "energy resources and environment," "education and culture," and "infrastructure" (see Figure 3-1). Health and social security emphasizes a complete health and sanitation system and ensure the safety of people's life. Industry and economy focuses on the emergence of new technologies and active innovation economy momentum. Energy resources and environment concentrate on green, low-carbon environments and strengthening of disaster prevention and mitigation capabilities. Education and culture promotes cultural and technological integration and continues to foster interdisciplinary talents. Infrastructure places emphasis on adjusting laws and regulations on science and technology and accelerating Taiwan's digital transformation. Therefore, this chapter presents response strategies to address the aforementioned issues. These strategies are expected to facilitate establishing competitive advantages so that Taiwan can keep its position as the world's leading innovator.

Figure 3-1. Five dimensions and 20 major issues

1. Health and Social Security

(1) Food Safety

A. Problems and Challenges

(A) Different departments are responsible for operating Taiwan's food safety management system. Although a reporting mechanism has been established, several parts of the documentation process are still performed manually, making it difficult to track the source and food product flow. Cross-departmental coordination and communication remain flawed, and food source tracking and early warning capability require further improvement.

(B) Functions of food product information system warrant continuous improvement. Currently, the government has set up a web portal to its food product information system and developed a school lunch protection network. In future, citizen needs can be used as the basis to continuously refine system functions and raise data application value. Regarding food inspection, different testing items and regulatory standards are applied to the same raw materials but different finished products. Business owners who are unfamiliar with products or laws tend to violate food safety related laws.

(C) Because the number of food safety inspectors in Taiwan is limited, the government is unable to provide support for the numerous, complex inspection tasks. In Taiwan, there were 200 health inspectors on average over the past 10 years (2008-2017), and this number is decreasing on a yearly basis. Health inspectors are also responsible for inspecting pharmaceutical administration, smoking health risk, and public health affairs. Workforce in charge of food safety tasks is limited, which impedes the deepening of food safety expertise, rendering the government unable to effectively meet demands and necessitating further improvement in testing quality.

B. Response Strategy: Building a food safety protection network and improving the health and well-being of citizens

(A) A complete food safety system promotes industrial value addition

Build in-house information platforms connecting food raw materials to sale processes, keep abreast of food flow, strengthen source tracking capability, and incorporate intelligent technologies to strengthen food safety early warning, enhance the safety of food raw materials and finished products by refining the food safety chain, and create industrial value.

(B) Reinforced horizontal integration reduces food safety risks

Continuously integrate cross-departmental resources, improve open information platform, include inquiries for regulatory standards, testing items, food product processes, hazardous substances in food products, and radioactive test information, strengthen food safety education for citizens, and increase food safety risk prevention capability.

(C) Using intelligent technologies to increase inspection capacity

Use intelligent technologies to improve inspection capacity, establish standard operating procedures (SOP), strengthen food safety management capability, optimize inspector training system, and enhance talent duty and implementation performance.

(2) Cybersecurity Risk

A. Problems and Challenges

(A) According to the Microsoft Security Intelligence Report[6], 6.4 people on average out of every 10 Taiwanese people opened emails containing malicious links in 2017. This is the highest in the world, suggesting a need to further raise Taiwanese people’s cybersecurity awareness. As digital and information systems become increasingly popular, cyberattacks and threats will continue to increase.

(B) The Cyber Security Management Act enforced in May 2018 prioritizes international exchange and cooperation. However, Taiwan is not a member state of cybersecurity related organizations, which prevents it from accessing firsthand cybersecurity intelligence and participating in the formulation of international cybersecurity standards. To accelerate the innovation and upgrading of Taiwanese industries, the Executive Yuan has launched the 5+2 industrial innovation plan to help industries to incorporate cybersecurity protection and designs in the process of developing innovative products or services, and leverage the synergistic power of guiding the innovation transformation of industries. In future, the

6 Microsoft, 2018, Microsoft Security Intelligence Report, Vol. 23, p. 40.

government should work toward establishing Taiwan's product safety brand image.

(C) Enterprises in Taiwan are not investing enough resources in cybersecurity protection. Their ability to inspect and diagnose cybersecurity incidents is also limited. The Executive Yuan has approved the Cybersecurity Industry Development Action Plan in March 2018. Through this plan, the government first sets an example by providing cybersecurity funds to foster cybersecurity industries, train cybersecurity talents, and raise the cybersecurity awareness of corporate organizations. In future, the government must continue to improve the industries' cybersecurity environment and fortify its cybersecurity protection network.

B. Response Strategy: Raising public awareness on cybersecurity and fortifying cybersecurity defense systems

(A) Training cybersecurity talents to balance industrial supply and demand

Raise people's cybersecurity awareness through propaganda and education system, build a needs-oriented cybersecurity training mechanism, increase the professional competency of cybersecurity talents, collect industrial, academic, and research resources, train interdisciplinary innovators in cybersecurity, develop mobile and flexible cybersecurity recruitment mechanisms, and balance industrial supply and demand for cybersecurity talents.

(B) Strengthening international exchange for a robust cybersecurity environment

Join international cybersecurity organizations, participate in public and private international cybersecurity conferences, keep track of trends in global cybersecurity development, encourage industries to provide resources, stay abreast of critical infrastructure protection (CIP) standards, continue to adjust cybersecurity laws, standards, and contingency mechanisms, and reinforce national cybersecurity defense systems; expand collaborations with other countries on cybersecurity, increase the international visibility of Taiwan's cybersecurity protection, implement national CIP, promulgate the Cyber Security Management Act, strengthen supply chain and integration, and build a complete cybersecurity ecosystem.

(C) A fully equipped infrastructure ensures greater industrial capacity

Formulate cybersecurity regulations for key industries, reinforce cybersecurity protection networks, promote interdisciplinary cybersecurity cooperation, build cybersecurity joint defense and intelligence sharing systems for critical infrastructures, improve cybersecurity integrated service platforms to fortify Taiwan's critical infrastructures, increase capacity of the government and industries to protect cybersecurity, boost the development of cybersecurity industries, and implement intelligent technologies to increase industrial competitiveness and value, thereby reinforcing Taiwan's critical infrastructures and the self-management capacity of cybersecurity industries.

(3) Allocation of Medical Resource

A. Problems and Challenges

(A) The service capacity of community-based clinics and pharmacies is limited. For example, patients must have a prescription to collect their medication in other areas, and there is a serious shortage of medical human resources in rural areas. Under these situations, health care quality cannot be effectively improved. Taiwan has numerous townships in short of emergency medical resources. Cases of major trauma, stroke, and other catastrophic illnesses must be transferred to other regions, which is time consuming and increases the risk of resuscitation failure.

(B) A major urban-rural gap exists in the distribution of medical resources. According to the statistical data of the Ministry of Health and Welfare (MOHW), offshore islands have the least number of medical practitioners in Taiwan per 10,000 population in 2016. Hualien County has a small population and the third highest number of health care professionals in Taiwan; however, large hospitals are located mostly in Hualien City. Therefore, medical resources are also unevenly distributed in Hualien.

B. Response Strategy: Increasing medical service capacity to develop telemedicine network

(A) Integrating information platform for more diverse services

Integrate health information service platforms, use intelligent technologies to track patients' health conditions, strengthen needs-oriented health care services, implement medical subsidy policies, improve the all-in-one functions of primary care clinics and mobile hospitals, and increase medical service capacity.

(B) Making use of regional resources to strengthen telemedicine services

Integrate the sources of regional hospitals, improve rural medical service networks, incorporate intelligent technologies for better medical service quality, implement health care localization, and construct a comprehensive cloud-based healthcare network.

(4) Epidemic Disease Prevention and Preventive Health Care

A. Problems and Challenges

(A) In 2017, the top 10 leading causes of death in Taiwan involved mostly chronic diseases. Chronic diseases cannot be addressed by health insurance alone; better diagnosis, treatment, and health care guidelines are required, and a comprehensive non-communicable disease prevention system must be developed. Although a health care classification system has been promoted for many years, it has not yet been fully implemented. Large medical centers and district hospitals cannot develop an effective health care system, and medical resources must be more efficiently used and integrated to ensure that the quality of medical resources is consistent for different level hospitals.

(B) The reporting architecture and monitoring systems established by Taiwan Centers for Disease Control since the epidemic outbreak of the severe acute respiratory syndrome (SARS) can no longer meet current epidemic prevention requirements. As pathogens increase in variety, national laboratories must assume a leading position, regularly incorporate international standard testing methods, continuously develop advanced testing technologies to treat new infectious diseases. Because population aging and birth rate decline are influencing Taiwan’s population structure, the government must establish national vaccination programs that afford economic benefits, meet epidemic prevention requirements, ensure the health of all ethnic groups, and are sustainable. The government must also continue to ensure its capacity to supply vaccines. The World Health Organization (WHO) encourages competent authorities to formulate national action plans to mitigate the threats of drug-resistant microorganisms. Large amount of medical resources is required for treating chronic diseases such as tuberculosis and AIDS. The Taiwanese government must continue to comply with international standards and implement new prevention and treatment strategies.

(C) A review of Taiwan's health-friendly measures (e.g., social housing, transport facilities, tax incentives, and family education) implemented in response to the declining birth rate problem shows that intelligent technologies can be incorporated to comprehensively improve child care environment.

B. Response Strategy: Strengthening public health system to perfect the social support system

(A) Strengthening preventive health care services to build a complete healthcare network

Implement systematic cancer precision medicine and prevention strategies, expand chronic disease management and care networks, promote healthy and nutritional diets, implement physical exercise and quit smoking/chewing betel nut programs, build a sound genetic and rare disease care network, use science and technology to strengthen holistic preventive health care works, mitigate the financial burden of non-communicable diseases, and improve the health quality and life expectancy of Taiwanese citizens; and help hospitals to integrate intelligent technologies, strengthen disease monitoring and warning capability, integrate central and local healthcare resources, keep health care quality consistent across all hospital levels, implement the sharing of healthcare resources, deepen home-based healthcare services, form an effective health care network, and develop home-based healthcare industries.

(B) Establishing a comprehensive epidemic prevention network for greater epidemic prevention capacity

First, integrate ministerial R&D capacity, continue to strengthen Taiwan's epidemic prevention system by using an all-in-one epidemic prevention strategy, actively participate in international health activities, and create opportunities that enable Taiwan to cooperate with other countries and join world health organizations; second, improve epidemic prevention information platforms by integrating cross-departmental resources, use cloud computing technologies, establish standard data exchange format, enhance reporting efficiency and accuracy, keep updating national epidemic information, increase epidemic early warning capability by using intelligent technologies, construct regional joint prevention networks, strengthen medical cooperation and exchange, and help epidemic prevention industries to establish global presence; and lastly, build national laboratories, construct national epidemic monitoring network by augmenting pathogen and gene databases, keep abreast of pathogen trends and drug resistance changes, develop and promote fast-acting agents/platforms, refine pathogen identification and drug resistance diagnosis, increase the efficiency of diagnosing communicable diseases, and use these outcomes as the empirical basis for disease treatment.

Conduct long-term follow-up on vaccine-preventable diseases and seroepidemiology, provide empirical evidence for vaccination policies, encourage the industrial, academic, and research sectors to invest in the R&D of vaccines for new communicable diseases, accelerate the increase in vaccination production rates, and use information technologies to strengthen prevention and inoculation management systems; formulate and implement cross-departmental integrated antibody drug resistance action plan, expand the scope of antibody resistance surveillance in Taiwan, and continuously refine control and prevention technologies for healthcare-related infections; and develop innovative strategies for tuberculosis and HIV screening and assess new drug and integrated care model to build evidence-based treatment database, and improve health care quality, thereby minimizing the consumption of healthcare resources and social burden.

(C) Integrating interdisciplinary resources to promote social innovation

Integrate the capacity and resources of the industrial, academic, and research sectors from a social needs perspective, promote collaboration between public and private sectors, cooperate with social affairs units, enhance health examination accessibility, and use intelligent technologies and big data analytics to determine the needs of different groups, develop medical and healthcare measures for women and children, construct a complete social support system, and create a safe, secure, and nursing child care environment.

(5) Accuracy of Public Online Information

A. Problems and Challenges

(A) Taiwanese citizens must further improve their literacy and the ability to recognize accurate information, so that they are not easily influenced by other, they know to make their own judgment only after seeing the whole picture, and they do not spread false information. In the long run, citizens must have the abilities to correctly recognize and judge the authenticity of a piece of information so that they do not easily share controversial information, thereby reducing the bandwagon effect. In future, national education systems should be used to continuously promote media literacy education and foster people's information literacy.

(B) Presently, government agencies have established rumor-refuting sections on their website. The National Communications Commission also assists with developing communication platforms for different stakeholders, including social media users, civic groups, and expert scholars. The Taiwan FactCheck Center, which was independently established by civic groups, follows the principles of openness, transparency, rigorousness, and accountability to check facts related to public affairs. However, disputable information online can never be checked as fast as it is spread.

B. Response Strategy: Improving citizens' media literacy and build a sound information ecosystem

(A) Strengthening media literacy education

Promote the revolution of media literacy education, strengthen citizens' information literacy, and improve everyone's media literacy by using different learning channels.

(B) Constructing a sound information ecosystem

Use intelligent technologies to facilitate information fact check and risk detection, and adjust related laws to strengthen the discipline and management of media, social network, and online platforms and build a sound information environment; and immediately refute and correct online rumors to accelerate the spread and dissemination of correct information, and open access to original data on the government's open data platform when issuing press release to refute a rumor so that members of the public understand the basis of government's decisions and spread the correct information.

(6) Geriatric and Dementia Health Care

A. Problems and Challenges

(A) The government has established long-term care information integration systems to perfect its healthcare infrastructures, and strengthened the links between health care and social welfare. However, long-term care related data are stored in different systems, making them difficult to access, which influences service efficiency and quality.

(B) According to MOHW statistics, the demand for care services is increasing on a yearly basis. To increase service capacity and care quality, the government should encourage long-term care operators to introduce auxiliary and application technologies to reduce the burden of caretakers.

(C) Caretaking tasks are complicated. Care related training generally involves institutional courses instead of professional training for specific needs. Taiwan still does not have enough professional caretakers, which is a problem that cannot be resolved in the short run.

B. Response Strategy: Integrating healthcare resources to complete the smart care network

(A) Increasing public and private collaborations to strengthen care networks

Complete the long-term care information integration system based on users' needs, forge stronger ties between the healthcare and social welfare systems, integrate local care resources, introduce intelligent technologies, track and ascertain local needs, continue to reinforce preventive services and their connection to smart healthcare systems, create a network of healthcare technological services, and integrate and analyze smart software programs to strengthen links and enhance the quality of geriatric and dementia health care.

(B) Promoting scientific and technological innovation to develop smart care services

Encourage industrial, academic, and research sectors to invest in the R&D of smart care technologies, promote the translation of related research outcomes into products and service models, complete safety certification and site validation, develop smart technologies to facilitate the scientific and technological R&D of individual health care services, and encourage health care units to introduce the aforementioned products and services to improve their healthcare efficiency and quality, reduce the social and medical burden of elderly patients and patients with dementia, alleviate the pressure experienced by caretakers, increase the life expectancy of Taiwanese citizens, and attract commitments to industrial and talent development.

(C) Improving talent training to increase care capacity

Integrate cross-departmental resources to improve the long-term care information integration system and strengthen care training systems, use intelligent technologies to reinforce care talent training, enhance care service quality, and reduce manpower requirements.

2. Industry and Economy

(1) Circular Economy

A. Problems and Challenges

(A) In recent years, the government has changed its waste management approach from end-of-pipe treatment to resource recycling and reuse. In future, transformation into a circular economy should be considered, and the entire waste management system should be designed according to substance lifecycle. Previously, Taiwan was focused on ascertaining the quantity and flow of wastes rather than collecting information on use of raw materials to complete the materials database. The government must rethink about the framework of implementing resource recycling and reuse to expedite the transformation process.

(B) Beginning in 2001, central authorities have been authorized to conduct waste recycling review and management tasks in accordance with the Waste Disposal Act. Since then, waste recycling rates have increased considerably. However, because wastes are recycled and reused, the technical or economic benefits seem to be limited. The rate of waste recycling has plateaued and is unlikely to increase further.

(C) Various industries in Taiwan are equipped with mature regrind technologies, although they still have more room for improvement in this regard.

(D) To encourage the adoption of environmentally friendly materials, the government has implemented policies for prioritizing the purchasing of environmentally friendly products. However, the incentives provided are still inadequate.

B. Response Strategy: Focusing on scientific and technological R&D to complete materials database and resource recycling laws and accelerate the implementation of circular economy

(A) Amending laws to strengthen scientific and technological applications

Integrated materials database and construct resource recycling platforms, conduct inventory of industrial wastes, improve waste tracking and recycling circular systems, adapt renewable resource (use of regrind) laws, and introduce intelligent technologies to strengthen supervision mechanism, thereby realizing a circular economy in which resources are recycled and sustained.

(B) Promoting cross-industry cooperation to develop innovative models

Set up a R&D section that provides information on recycling technologies and material innovation, integrate the capacities of industrial, public, academic, research, state-owned business, and private sectors, and invest in the R&D of innovative materials; and integrate regional energy resources, strengthen waste energy recycling and reuse, improve the development of product designs or manufacturing technologies for managing sources to reduce use of raw materials, build a cross-industry cooperation platform, develop alternative materials, reuse substances in original processes, use innovative technologies to produce green materials for downstream industries, simultaneously implement clean production, strengthen waste reduction, develop green technologies and conserve resources, improve measures, and implement a producer joint accountability system.

(C) Improving circular design for a complete circular system

Focus on new materials industries, incorporate circular economy concepts—process improvement, redesigning, and resource recycling and reuse, and develop and redesign innovative recycled materials, technologies to use recycled resources innovatively, high-value circular ecological chain innovation model, and intelligent application technologies; and improve multi-level designs of product applications, regrind treatment technologies, and output quality, and use intelligent technologies to build an innovative resource recycling model or business model, thereby improving resource circular systems.

(D) Increasing resource productivity and boosting the green economy

Help industries to incorporate green designs and clean production processes, highlight the green value of products and prolong product lifecycle, and integrate the material flow and energy flow of plant processes to increase plants' reuse rate.

(2) New Financial Technology (FinTech)

A. Problems and Challenges

(A) FinTech laws and regulations are rigid. Laws relating to digital identity authentication, big data analytics, and financial regulatory technologies must be amended as soon as possible. Presently, a financial regulatory sandbox mechanism has been implemented, but financial laws related to it must be reviewed and adjusted to further improve financial innovation ecosystems.

(B) The prevalence of payment services has influenced people's spending habits and the mode of operation of financial systems. Meanwhile, business owners have limited access to resources and data, which discourage them from using intelligent technologies to conduct value-added analysis and introduce one-stop services. This problem hinders the upgrading of financial services.

(C) Universities and colleges have established FinTech research centers. If these centers can be connected to industries to forge stronger ties among industries, academia, and research institutes, financial industries can more quickly establish their core competitiveness.

(D) Financial services combined with new technological applications can streamline the workforce, simplify service processes, and increase quality. Therefore, traditional financial service personnel should be trained to hone their skills and international exposure. Financial operators should increase their capacity in data analysis, technological innovation, and digital application, and also recruit professionals who are well-versed in technologies, finance, and law.

B. Response Strategy: Improving the financial innovation infrastructure to build a strong pool of FinTech specialists

(A) Accelerating financial law amendments

Help regulatory personnel to quickly understand how new technological and business models operate by using FinTech innovative experimentation mechanisms and the regulatory service of FinTechSpace, think about the directions and measures of regulatory amendments, formulate innovative experimentation exemption laws and management regulations within the specific scope and period of experimentation, expedite FinTech development, review and revise finance related laws according to innovative experimentation situations providing that the financial market is stable and consumer rights are protected, and accelerate the R&D and application of new financial business models and technologies to improve financial service performance.

(B) Enhancing a cross-industry platform of financial services

Strengthen data setup for industry information disclosure platforms, create platforms on which different industries can cooperate to provide financial services, add more service items and resources to FinTechSpace, and provide co-working office spaces and resources according to market needs so that FinTech startups can receive appropriate assistance at different stages of development; and establish digital sandbox platforms to encourage financial institutions to cooperate with other industries, integrate data and application program interfaces, and accelerate R&D and application in relevant domains.

(C) Promoting interdisciplinary resource integration to foster and support startup companies

Encourage industries to invest in financial innovation activities and join forces with academic and research sectors to integrate resources and capacity to establish alliance and build FinTech laboratories so that they can improve their FinTech innovation and application capabilities through technology exchange and resource sharing; and set an example by investing in FinTech startups to drive and develop FinTech innovations and construct a positive ecosystem.

(D) Extending global presence to expand market and train talents

Organize FinTech exhibitions, provide international exchange platforms, showcase Taiwan's R&D outcomes, assist business owners to develop business opportunities, demonstrate the energy and capability of Taiwan's FinTech ecosystems, thereby attracting foreign investments to release Taiwan's financial innovation capacity; and create learning opportunities through multinational talent interaction and exchange, expand the cultivation of FinTech and interdisciplinary professionals, strengthen digital skills and expertise, and build a strong pool of FinTech experts.

(3) New Business Models

A. Problems and Challenges

(A) New business models involve aspects related to the activities of daily living (e.g., food, clothing, accommodation, transport, education, entertainment, and health care). Different types of businesses are subject to different laws and regulations. Regulatory amendments cannot keep up with the pace at which new services are being introduced. This problem negatively influences the development of startup companies and the penetration of new services. In other words, regulatory mechanisms and tax problems must be comprehensively considered. In addition, Taiwan has limited energy resources and therefore must urgently find new business models for renewable energy.

(B) Cloud service systems are used in sharing economy platform. Servers storing user information and transaction information are typically located in other countries. In the event of consumer dispute and information leak, citizens are not fully protected, necessitating the development of a service provider verification and reputation mechanism. Moreover, insurance and security issues must be addressed first in case collaborative economy becomes increasingly popular in the future.

B. Response Strategy: Improving innovative economy infrastructure to promote the development of new business models

(A) Encouraging cross-industry communication and adaptation laws and regulations

Collect public opinions, build cross-industry communication platforms, cohere consensus and resolve disputes, accelerate the amendment of laws to create an environment conducive to the development of innovative business models, learn from the experiences of community renewable energy projects in Europe, expedite the promotion of new operating models, and underline the features of green energy industries.

(B) Improving service mechanisms to protect the interests and rights of Taiwanese people

Formulate complete inspection processes and safety protection mechanisms for risky business activities, fulfill obligations to protect the rights of buyers and sellers, protect the privacy and safety of citizens, and implement measures on business taxation, labor insurance, and health insurance by referring to the "European Agenda for the Collaborative Economy" to meet the needs of industries and societies in the future, thereby boosting the development of collaborative economy.

(4) Urban-Rural Gap

A. Problems and Challenges

(A) Urban and rural development problems are the jurisdiction of different ministerial departments and local governments. These problems should be addressed with the help of different industries. Although the government has implemented key industrial innovation plans, the central and local authorities are still lacking platforms for interdisciplinary cooperation in local industrial development and new industry planning. Consequently, competent authorities may have different policy understandings, which will negatively influence the innovation of regional industries.

(B) To bring about balanced development throughout Taiwan, the government has approved the Administrative Division Act (draft) in May 2018. The draft provides governments of all levels with a legal basis for handling administrative division tasks to properly distribute administrative resources and improve problems relating to local governance predicaments and the urban-rural gap. However, townships in Taiwan have different customs, cultural characteristics, and infrastructures, and the incentives offered are not enough to facilitate the merging of different regions.

(C) Implemented policies are focused on the construction of infrastructures. However, population migration is a factor contributing to the urban-rural gap. Local resources cannot be effectively integrated, and incentives are not good enough to attract young adults to work in rural areas.

B. Response Strategy: Developing innovative operation models to create ecosystems that feature local characteristics

(A) Strengthening local inter-governmental cooperation to boost the local economy

Deepen the cooperative relationship between central and local governments, integrate the resources of ministerial departments and local industries, relax laws governing the development of local placemaking businesses, implement place-oriented innovation mechanisms, and solve the problems of local industries.

(B) Implementing administrative division to promote local symbiosis

Consider the conditions and uniqueness of regional development, implement the division of administrative areas, incorporate intelligent technologies to develop key industrial clusters, continue to promote local symbiosis, increase productivity and marketing capability, and create the value of local areas.

(C) Integrating regional resources and creating local characteristics

Integrate the resources of local industries, schools, research institutes, and private businesses, develop innovation ecosystems that feature cultural and historical characteristics, encourage local residents and young adults to start a new company, and organize promotional and sales events on different platforms to shape local cultural brand.

(5) Industrial Upgrade and Transformation Amid Waves of AI Revolution

A. Problems and Challenges

(A) In response to policies promoting the relocation of American manufacturing companies back to the United States and the increasingly more customization orders, industries must expedite their strive toward high-value development through integration with up/mid/downstream systems to create a high-mix low-volume (HMLV) manufacturing model that facilitates quick order acceptance, flexible production, and stable delivery.

(B) According to Taiwan's Ministry of Economic Affairs (MOEA)[7], 97.7% of enterprises in Taiwan are SMEs with limited innovation resources. The level of internationalization and digital capability of SMEs require further improvement. Given the rapid changes in global industrial ecosystems because of intelligent technologies, incentive policies or outside resources are urgently required to strengthen the technological capabilities of SMEs, accumulate intelligent capitals, and accelerate the complete adoption of intelligent technologies in production models.

(C) The Future of Jobs published by the WEF in September 2018 indicated that AI technologies are expected to create 133 million new roles but cause 75 million jobs to be displaced by 2022. For this reason, the Taiwanese government must keep abreast of changes in the global economic and trade environment, understand the talent distribution and supply-demand conditions of industries, and formulate related policies in advance to prepare for future demands for talents.

B. Response Strategy: Reshaping the industry value change to accelerate industrial upgrade and transformation

(A) Building information platform for more effective vertical integration

Build information integration platforms for key export industries to increase the timeliness of product development, production, and sales, provide business partners with suggestions, and effectively meet market demands.

(B) Integrating scientific research capacity to build core competencies

Introduce the R&D capacities of the academic research sector according to different industry requirements, expedite the complete adoption of intelligent technologies in industries, and encourage industries to establish mechanisms for innovation cooperation, promote knowledge, technology, and talent exchange, and drive industrial transformation.

(C) Forging international ties to reinforce talent cultivation

Integrate ministerial talent databases, link them to international business intelligence platforms, keep abreast of talent supply-

7 Ministry of Economic Affairs, 2018 Small and Medium-Sized Enterprise Whitepaper.

demand situations and distributions in Taiwan as well as the future development trends of global industries, promote talent training policies for learning future skills, and accumulate industries' human capital.

3. Energy Resources and Environment

(1) Environmental Quality

A. Problems and Challenges

(A) Taiwan has the 16th highest population density[8] in the world (655 people/km^2). Specifically, eight counties and cities in Taiwan were populated by more than 1,100 people per square kilometers[9]. A large number of people are concentrated in metropolitan areas, generating an impact on the living environment and worsening environmental pollution. The Environmental Protection Administration (EPA) has deployed environmental IoT sensors. However, audit capacity and environmental governance must still be improved further.

(B) Considering the reduction of greenhouse gas (GHG) emissions and air pollution in Taiwan and overseas, the Taiwanese government promulgated the Greenhouse Gas Reduction Action Plan[10] in March 2018. The plan aims to reduce GHG emissions intensity by 20% below 2005 levels by 2030 and provides the control objectives of six departments: energy, manufacturing, transportation, real estate, agriculture, and environment. These objectives can be achieved only through collaborative efforts between the government, industrial sector, and the general public. However, several industries are already long-time participants in GHG voluntary reduction programs. If they cannot turn to adopting the future reduction limit, the past efforts of these vendors will be nullified, thereby reducing participation incentives and reduction effectiveness.

(C) In recent years, the government has actively promoted a circular economy, developed clean production and green technologies, strengthened energy resource recycling systems, and implemented green industry development policies as well as energy conservation

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[8] World Population Review, 2018, World Countries by Population Density 2018.

[9] Counties and cities with more than 1,100 people/km^2 in Taiwan were New Taipei City, Taipei City, Taoyuan City, Taichung City, Changhua County, Keelung City, Hsinchu City, and Chiayi City. Data source: Department of Household Registry, Ministry of Interior (statistics as of October 2018).

[10] The 2018 Greenhouse Gas Reduction Action Plan, EPA, Executive Yuan.

and carbon reduction policies. However, measures for disposing of industrial wastes, for which recycling technologies are nonexistent, are still ineffective, and existing waste treatment plants have limited capacity to process wastes. Consequently, manufacturers and vendors have to store large volumes of waste in house, which negatively affects the plants' normal operation and surrounding environment. In addition, problems in the management of radioactive wastes must be considered to keep the environment clean and citizens safe.

B. Response Strategy: Strengthening resilience in environmental governance and building a low-carbon living environment

(A) Deploying networks of environmental sensors to foster stronger audit capacity

Develop satellite remote sensing technologies to enhance high-temporal/spatial resolution environmental monitoring capabilities; deploy monitoring stations and automatic sensors in seawater areas and terrestrial areas with high population flow and density to collect a region's environmental data such as air and water bodies; and integrate cross-departmental resources to strengthen environmental monitoring capability, introduce intelligent technologies, improve pollution source tracking capability, increase audit capacity and environmental change early warning capability, and instantly initiate related response behaviors.

(B) Increasing GHG reduction incentives to encourage industry participation

Consider industry characteristics, increase GHG reduction incentives, promote green financing, provide low-carbon rewards and subsidy measures, revise the reduction objectives of various departments and industries accordingly, establish conversion limit for effective voluntary reduction, define fair and suitable reduction responsibilities, encourage industry participation, and reward use of low-carbon products to achieve the country's GHG reduction goals. Each accountable department must commit to related reduction strategic support research and industry guidance plans to establish feasible plans that help Taiwan to achieve its sustainable development goals.

(C) Reinforcing recycling technologies to increase the benefits of demonstration parks

Integrate industry-academic-research cooperation platforms, reinforce the R&D and innovation of green technologies and alternative materials for resource recycling, effectively recycle industrial resources, accumulate mature product experiences, create high-value supply chain, drive industrial revolution and business transformation, realize the concept of sustainable resources, promote waste recycling, and encourage cross-departmental cooperation to plan a circular economy demonstration park and further expand it nationwide to increase waste treatment capacity, ensure smooth waste disposal channels, and accelerate the development of nuclear waste storage and disposal technologies to meet international safety standards and increase decision confidence and social acceptance.

(2) Energy Supply and Demand

A. Problems and Challenges

(A) Taiwan is not energy self-sufficient (2.33% in 2017)[11]. For a long time, the country has been relying on imports. Because price and supply are easily affected by the global environment, the occurrence of energy crisis or surge in international oil prices often negatively impact Taiwan’s society and economy. Given the considerable influence of power supply on the economy and livelihood, ensuring stable power supply is still the government’s priority.

(B) The government proposed energy transformation objectives in 2016, stating that by 2025, the country will generate 50%, 30%, and 20% of its electricity from natural gas, fuel, and renewable energy, respectively. A complete route plan based primarily on solar power and offshore wind power is already in place. So far, the progress of the plan has been successful, despite a few challenges still to be addressed, such as whether measures, including inventory of solar-powered land and feeder installation, can be completed on schedule.

(C) Taiwan employs an isolated island microgrid system, which adopts one-way centralized electricity generation approach. If a problem occurs in the transmission network, large-range power outage is

[11] Energy Supply and Demand Overview Analysis (updated on October 15, 2018), Bureau of Energy, MOEA

likely to occur. Thus, traditional grid systems must be upgraded. Renewable energy is intermittent and unstable. If renewable energy is integrated into existing power grids, unstable power supply results when capacity percentage increases, subsequently affecting the overall power quality.

B. Response Strategy: Reinforcing energy conservation efforts and diverse innovation initiatives to build smart grid ecosystems

(A) Implementing energy conservation and carbon reduction to increase energy efficiency

Develop an energy efficiency improvement service model, strengthen the R&D, incorporation, and integration of energy-saving components, equipment and system technologies, encourage industries to recycle and reuse energy resources (heat, water, etc.) to increase energy efficiency, and encourage academic research sectors to cooperate with local industries.

(B) Introducing innovation models to promote energy development

Strengthen the promotion of renewable energy diversification (hydropower, geothermal energy, biofuel, renewable energy-converted hydrogen, offshore wind, and marine energy), promote the R&D of renewable energy innovation technologies, combine innovative business models and testing ground verification to generate synergy, increase the amount of electricity generated by renewable energy, and continue to develop nuclear back-end technologies.

(C) Strengthening smart grids to ensure stable power supply

Integrate the capacities of industries, academia, and research institutes, strengthen the R&D of smart grid technologies, accelerate research on power consumption big data and industry demand response through smart meter deployment, develop technologies to predict and regulate electricity generated from renewable energy, expand the scale of outlying island microgrids and increase application benefits, strengthen regional power distribution management and energy storage systems, perfect the smart grid environment, and increase the stability of power supply systems.

(3) Disaster Risk Management

A. Problems and Challenges

(A) Current climate change policies are based on scientific evaluations; however, the eight domains of the Adaptation Strategy to Climate Change in Taiwan are characterized by large scale, large space, different industries, and composite risks and use limited scientific instruments for measurement. In other words, the adaptation strategy cannot be used to address scientific uncertainty problems. Meanwhile, Taiwan's various policies influence societal development. The uncertainties in these governance practices and their impact on the management of disaster risks cannot be completely covered by existing scientific evaluation methods.

(B) Presently, Taiwan has performed potential analysis on a few types of disasters; however, its prevention measures are designed mostly to provide early warning for stronger earthquakes. In future, the government should also develop innovative products for collecting, analyzing, and assessing intelligence data on torrential rain and other disasters. This initiative will involve sensor R&D and deployment, big data analytics, data accessibility, and innovative applications.

B. Response Strategy: Developing cross-industry risk governance framework to increase early disaster warning capacity

(A) Developing cross-industry risk governance framework to optimize disaster risk control

Develop a cross-industry risk governance framework to initiate interdisciplinary dialogues on the knowledge and governance of climate change and coping strategies, incorporate policy decision-making processes, and engage in interdisciplinary collaboration and co-creation to formulate disaster risk control and adaptive strategy in line with national spatial plans and societal needs and promote the construction of a resilient city.

(B) Collecting and using disaster-related intelligence to strengthen disaster early warning capacity and cultivate related industries

Collective an extensive range of intelligence, strengthen the monitoring and analysis of meteorological, climate, and marine forecasts, refine disaster weather warning technologies, enhance seismic testing and reporting performance and promote earthquake prediction research, use big data analytics to reinforce disaster warning capability, open access to data to encourage the R&D of related products and services, foster disaster warning industries, and export them to neighboring countries; and combine the capacity of different industries and modern technologies, strengthen regional responsibility and adaptability, integrate cross-industry disaster prevention cooperation mechanism construct disaster contingency systems, collate disaster-related intelligence and inventory of anti-disaster requirements, and effectively maximize the capacities of different industries by using and integrating the latest synchronized information to further enhance a region's ability to respond and adapt to climate change and disaster risks.

4. Education and Culture

(1) Interdisciplinary Integration of Culture, Science, and Technology

A. Problems and Challenges

(A) Cultural preservation should focus on whole systems and local contexts and be rooted in the daily activities of contemporary people. The remanufacturing and diverse use of "cultural property" (which refers to assets of cultural value from the point of view of history, art or science) specifically refer to the effective "collection, storage, acquisition, and use" of government digital platforms and cultural contents. Science and technology are urgently required to strengthen the preservation, research, exhibition, performance, teaching, application, and authorization of cultural heritage to accumulate, continue, and expedite the development of Taiwan's genuine culture.

(B) The sustainable development and continuous innovation of a culture require a foundation in professional and diverse talent cultivation. The role of an artist must be a catalyst for stimulating and inducing innovation. The creation of cultural content must be actively integrated with local characteristics, cultural contents, and existing clusters of dominant industries in Taiwan to rely on the capacity of existing industries, inject new energy, and create new products and services.

(C) Cultural communication enables people to understand and appreciate cultural property and cultural contents, and actively participate in and support cultural development. The advancement of digital technologies has created new cultural experiences so that scholars and lay-people alike can appreciate and even interact with creative art works and audio contents online or by visiting exhibitions.

(D) Cultural and creative industries require systematic support and plans to not only support the development of up/mid/downstream industries, but also strengthen their interaction and ties in order to form a mutually cooperative industry chain and develop a positive ecosystem. The government can encourage industrial development by offering financing and tax incentives, establish service platforms that help vendors to match and find resources, and learn from the experiences of South Korea, where culture, science, and technology are integrated to create value and production value.

B. Response Strategy: Implementing culture, science and technology policies to build an interdisciplinary ecosystem

(A) Promoting the preservation and revitalization of cultural property to build a smart culture-oriented city

Build national memory and local knowledge vase, present Taiwan’s cultural subjectivity from diverse perspective, construct cultural memory open platform mechanisms, promote public participation mechanism for a digital era, interpret and translate local knowledge, and open data access to encourage the development and innovation of value-added applications; strengthen technologies to preserve, maintain, and repair cultural property, introduce IoT technologies, and develop cultural property digital surveillance system; and establish a cultural heritage art archives collection database and digital cultural integration platform featuring functions to preserve, exhibit, research, apply, authorize, and trade cultural property, open links, and build communities, connect to and expand existing database functions, conduct cultural translation and inclusive innovation, and promote the innovative services of a smart culture-oriented city.

(B) Training and matching interdisciplinary professionals to establish a new academic and research paradigm

Use new technologies to train professional talents in art and culture, strengthen interdisciplinary training and matchmaking, and conduct cultural translation and inclusive innovation; continue to build a digital cultural information and investigational database and encourage exploration of social transformation and value change in a high-tech era.

(C) Encouraging cultural creation and value-added application to enhance citizens' cultural literacy

Develop science, technology and art demonstration park, encourage innovative projects infusing elements of science, technology and art, integrate culture and art into key science and technology industries in Taiwan, produce interdisciplinary products, drive industrial demands, and facilitate the establishment of world-class science, technology and arts teams so that art acts as the catalyst for boosting industrial transformation; research and develop shared new media materials and post-special effects technologies to help content industries to cross funding thresholds, and use AI and other information technologies to develop intelligent content creation tools and overcome content creation bottlenecks; and make full use of raw materials to create contents that resonate with local characteristics and international markets, strengthen content intellectual property, and encourage diverse value-added applications.

(D) Establishing new cultural communication platforms to catalyze the development of a cultural content innovation ecosystem

Develop new media models in line with technological convergence and digital transformation trends and the characteristics of 5G action plan (i.e., high frequency bands, low latency, and full view) to promote content penetration on cultural communication platforms, and accelerate the development of cultural content innovation ecosystems; research and develop experience technologies to promote new cultural entertainment industries, use data science to explore cultural spending preference so that cultural products are flexibly produced to keep up with market trends, and promote international export to increase the market dominance of Chinese-speaking culture contents; adopt design thinking and interdisciplinary integration approaches to convert the designs of cultural contents and combine them with science and technology to promote business innovation, public service innovation, and social innovation, establish international innovation service models, and integrate them into people's everyday life; and develop one-stop service and experimentation platforms to help vendors to seek resources, solicit funds, technologies, spaces, infrastructures, and interdisciplinary talents, use art archive database and big data analytic results, combine augmented reality and digital technologies to conduct diverse creative experiments, build ecosystems in which culture, science, and technology are sustainably developed, and enhance cultural value and production value.

(2) Cultivation and Recruitment of High-Caliber Professionals

A. Problems and Challenges

(A) Regarding talents in science and technology, the decline in birth rate has reduced the need for higher education educators. Because business organizations prefer to not hire people with PhD degree, the career prospects of these people are unknown. Consequently, increasingly more people are unwilling to study PhD program, resulting in a continuous decline in the number of PhD talents. Concurrently, the Ministry of Science and Technology (MOST) has introduced a number of subsidy, training, and recruitment programs for PhD researchers; however, low salary offers do not attract talented employees to work for a company or to stay working for the company. In addition, the international exchange of talents still require further improvement.

(B) Regarding industry talents, the gap in the supply and demand for industry talents underlines the continuous need to cultivate, retain, and recruit talented professionals. Concerning cultivation, the theory-practice gap must be closed to ensure that the cultivated professional talents can be employed by industries. In terms of retention and recruitment, the government should increase base salary, relax related laws, and strengthen the function of single service windows so that industries can attract and recruit domestic and foreign talents, thereby boosting industrial development. Meanwhile, the government should also conduct talent demand surveys of key industries and formulate training programs to provide key industries with a rich supply of professional talents.

B. Response Strategy: Cultivating and recruiting high-caliber R&D talents to strengthen the innovation of science and technology industries

(A) Supporting and recruiting high-caliber R&D talents to forge stronger science and technology capacity and industry R&D capacity

Accelerate higher education reform and increase higher education funding to strengthen the innovation and R&D capacity of higher education institutes; develop high-caliber talent databases to keep track of the whereabouts of PhD graduates and the supply and demand for PhD graduates; provide scholarships to PhD graduates to motivate Taiwanese and foreign students to further their study; encourage PhD students and postdoc students to participate in international exchange and research programs and continuously cultivate new generations of scientific researchers; and increase incentives for encouraging PhD students and postdoc students to take part in industry-academia cooperation projects, guide high-caliber talents to work in industries, and increase industries' capacity in R&D and innovation.

(B) Cultivating and recruiting professionals to facilitate industrial transformation

Promote industry-academia cooperation PhD talent cultivation systems, cultivate a pool of high-caliber professionals as needed by industries, monitor the trends, current status, and distribution of industry talents, and actively recruit high-profile talents from Taiwan and overseas.

5. Infrastructure

(1) Smart City

A. Problems and Challenges

(A) Regarding planning, a smart city refers to a city that creatively uses information and technological tools to solve complex urban management problems. The entire process of urban development, from source planning to end operation management, interlinked to each other. In other words, a city's comprehensive plan combining actual needs and development vision is the first step to success. Numerous cities around the world use different forecasting models and data to conduct planning. However, data analysis is not effectively used to plan smart city promotion programs.

(B) Regarding implementation, various county and city governments in Taiwan typically outsource their projects or allocate budget according to trending topics. Pressured by the need to deliver good policy performance, urban administrators are focused on implementing short-term hardware constructions, which are not yielding the desired outcomes because of various reasons. In future, the Taiwanese government can consider setting up a center for the advancement of smart cities, similar to the Future City Catapult in the United Kingdom, which is a government supported and privately funded center. By cooperating with local governments, this type of center can use open data and public data or other assets to call for creative project proposals, establish positive ecosystems and diverse innovation capacity, gain experiences in business model development, and forge cooperative and reciprocal ties between the public and private sectors. Thus, the government can not only achieve the vision of building a smart city and township, but also use key practical knowledge (i.e., know-how) to vie for smart city business opportunities from countries that are densely populated by East Asian and Southeast Asian people.

(C) Regarding management, because smart cities have numerous interconnected problems that need to be addressed, solely relying on technological applications will result in collage-like "semi-smart" plans that cannot be effectively implemented. Currently, the government has begun establishing environmental sensor networks and map service clouds. Although some government projects have integrated plans to provide disaster protection and air quality monitoring, there are still many applications to be actively developed for other aspects concerning people's everyday life.

B. Response Strategy: Strategy: Perfecting smart city planning and uniting public and private forces to develop an ecosystem of innovation

(A) Effectively integrating data for comprehensive planning

Gather the resources of central and local authorities, keep abreast of local demands, establish and accumulate urban data and information, and conduct comprehensive smart city planning through data analysis.

(B) Combining the capacities of public and private sectors to develop business models

Unite the forces of the public and private sectors, use the innovation capacity of private companies as well as open data and other assets, build an integrated service platform, develop innovation applications and services for a smart city, and foster related industries.

(C) Establishing a complete set of evaluation indicators to facilitate smart city development

Set up an evaluation indicator system based on local needs and local characteristics to facilitate the effective implementation of a smart city.

(2) Rural Broadband Gap

A. Problems and Challenges

(A) Taiwan's ICT is continuously advancing. According to WEF[12], Taiwan's networked readiness index 2016 ranked 19th in the world and 4th in Asia; however, Taiwan performed unfavorably in efficiency of legal system in settling disputes and effectiveness of law-making bodies, both ranking after the 100th place. Although a shared open telecommunication infrastructure can reduce rural setup cost and maximize the benefits of existing facilities, legal barriers can obstruct the promotion of a joint station approach.

(B) On September 12, 2017, the National Communications Commission in Taiwan amended "Charge Standards of Utilization Fee of Radio Frequency" by adding a joint charge mechanism based on the rural population coverage of high-speed base stations in rural areas. The mechanism provides discounted utilization fee as incentive for vendors to provide high-speed base stations and mobile bandwidth services in rural areas. In the third round of spectrum auction for 4G launched in April 2018, vendors are asked to increase the population coverage and the number of high-speed base stations in rural areas in the next five years. This increase is expected to greatly enhance the coverage rate of mobile broadband networks. Considering that digital services in rural areas are seldom used by residents, the government must contemplate on how to increase the penetration

[12] WEF, The Global Information Technology Report 2016.

rate of digital application services, close the digital gap between urban and rural areas, and create greater local value.

B. Response Strategy: Strengthening rural digital infrastructures to popularize digital application services

(A) Strengthening local inter-governmental cooperation to maximize benefits

Strengthen cooperation between central and local governments, eliminate regulatory problems relating to telecommunication infrastructures, enhance operating efficiency, and combine diverse technologies to strengthen transmission rate, expand the scope of transmission, and increase the rural population coverage rate of mobile broadband networks.

(B) Promoting local digital application to drive regional development

Integrate cross-industry resources, consider local characteristics, develop physically and virtually integrated digital services, provide free outdoor Internet services for indigenous people, and plan testing grounds to accelerate the development of local innovative application services, create digital service networks in rural areas, and boost local economic development, thereby improving the quality of life of rural residents.

(3) Completely Intelligent Transportation

A. Problems and Challenges

(A) According to the Ministry of Interior (MOI), the number of road traffic accidents in Taiwan is increasing on a yearly basis. A review of serious transportation accidents (e.g., the TransAsia Airways Flight 222, the TransAsia Airways Flight 235, and the Puyuma express derailment) in Taiwan over the year underlines the importance of safety to the effective operation of transportation systems.

(B) The Ministry of Transportations and Communications (MOTC) established the Public Transport Data eXchange (PTX) platform, providing the general public with value-added applications. The platform can be improved further by integrating with information of different domains. Because extant application tools are characterized by a single location, single service, and specific transportation vehicle, these tools still have room for continuous improvement.

(C) The MOTC's investigation report[13] showed that in 2016 almost 70% of citizens rode motorcycles and drove self-owned sedan as their main mode of transportation, whereas less than 20% of citizens traveled by using public transport.

B. Response Strategy: Strengthening the intelligent transportation system to perfect regional transportation network

(A) Reinforcing transportation monitoring to increase transportation safety

Introduce intelligent technologies to perfect transportation monitoring systems that automatically send early warning signals, thereby enhancing the safety of transportation systems and reducing traffic accidents.

(B) Strengthening system development to diversify services

Develop and strengthen the functions of application tools with users' need at the core, and continue to integrate open traffic data, encourage interdisciplinary cooperation between public and private sectors, implement needs-oriented innovation and R&D, and develop the intelligent transportation industry.

(C) Invigorating local resources to increase transportation capacity

Strengthen links to regional resources, keep abreast and satisfy local travel transportation needs, promote public-private cooperation, introduce intelligent technologies, develop innovative operation models, improve regional intelligent transportation systems, and increase public transportation use.

(4) Scientific and Technological Development and Regulatory Adaptation

A. Problems and Challenges

(A) The rapid development of science and technology is accompanied by increasingly more risk problems, particularly in genetic engineering technologies. Compared with other technologies, genetic engineering involves riskier R&D processes and high-tech applications, which are associated with not only scientific uncertainties but also disputes that these technologies destroy the

[13] MOTC, 2017, Survey of Daily Use of Transportation Modes.

ecosystems. In particular, new biotechnologies include gene sequencing, stem cells, gene splicing, cloning, and genetic modification. The risks arising from these technologies cannot be controlled, calculated, and compensated by using conventional methods[14]. The emergence of these new biotechnologies brings a ray of hope for patients with diseases that are untreatable by conventional medical techniques. How to strike a balance between the potential benefits and potential impacts of new technologies is a topic meriting immediate attention.

(B) The development of science and technology (e.g., AI, robot, autonomous vehicles) has led to disputes regarding ethics, rights, and obligations. For instance, should robots be granted the same legal rights as human, such as the right to political participation and social benefits? If robots can enjoy social benefits, who should assume the obligations (e.g., paying tax)? How should the accessories and affiliated economic benefits of robots (including robots and AI) be distributed? Robots are not necessarily fair and objective, and bias and discrimination in AI algorithms will influence results. If decisions are based on these results, how should the resulting impact be treated? How should the privacy of sensitive personal information (e.g., medical information) be protected? Should there be the "right to be forgotten" and the "right to erasure"? Who should bear the consequences of the impact generated by robots (e.g., large-scale unemployment, widened wealth gap)? In future, unmanned vehicles will be integrated with military technologies, becoming highly lethal military weapons. How should the use of these weapons be monitored or avoided?

[14] Kui-Tian Chou, 2002, Globalization of Genetic Science and Technology and Local Social Risks, *Science Development*, Issue 353, p.32-39; Shu-Mei Tang, 2011, On the Legal Risks of New Biotechnologies: The Predicaments of the Taiwan Biobank, *Asia University Finance Law Book Series (1): Legal Risk Management*, p.443-493.

B. Response Strategy: Strengthening the assessment and communication of science and technology legal risks to clarify legal disputes pertaining to the development of new science and technologies

(A) Establishing a system to communicate and assess science and technology legal risks to balance the risks and benefits of scientific and technological development

Regarding regulatory amendments, provide sufficient information on potential risks, acquire general consensus through communication, conduct risk assessment and control, establish risk analysis systems for the potential risks and benefits of new technologies, and improve and institutionalize procedures and mechanisms for risk assessment, management, and communication; and relax the laws pertaining to related industries, discuss and expand the scope of technological applications, and expedite the promotion of industrial innovations such as green energy technologies, unmanned vehicles, and circular industry.

(B) Clarifying disputes related to the ethics and laws of new technologies while ensuring protection of rights and interest and scientific and technological innovation

Deduce possible scenarios regarding ethical and legal disputes derived from new science and technologies, conduct research and analysis on related legal issues, clarify ethical standards, responsibilities, and rights, and establish complete data processing procedures that account for both the protection of personal privacy and the development of intelligent technologies.

Chapter 4. Scientific Research and Technological Development

In formulating policies for science and technology, policy makers but not only consider current societal needs, but also lay a foundation in scientific research for future development. Through science and technology policies and budget allocation, the government should support science, technology, and innovation according to industrial requirements and use technological knowledge to drive industrial transformation, which in turn boosts economic growth, thereby demonstrating the "small economy, smart strategy" to "build a nation by using science and technology." This chapter is composed of three sections. Section 1 "Science and Technology Development Trends" describes the current trends in the development of science and technology. Section 2 analyzes the international competitiveness of Taiwan in academic and technological domains. Section 3 presents the highlights of Taiwan's future scientific research plans.

1. Science and Technology Development Trends

This Roadmap organizes the inputs of different countries in science and technology to elucidate the technological development directions of various countries. Science and technology development trends reports published by international academic and research institutes are collected to analyze the technologies developed by industries and the scientific research concerns of the academic and research sectors. Finally, this Roadmap presents the science and technology projects in which Taiwan should invest in the next five to ten years.

The academic and research institutes in various countries around the world are paying attention to issues related to life science, health care and maintenance, environmental sustainability, intelligent technologies, exploring nature, and materials development. The scientific research focus of public sectors in different countries can serve as reference for Taiwan's future science and technology plans. For example, in July 2018, Japan's Council for Science, Technology and Innovation (CSTI) launched the 2nd Strategic Innovation Promotion Program (SIP), which plans to realize the technical basis of Society 5.0 by investing in projects related to next-generation network technologies, IoT, cybersecurity, new materials, smart medicine, low-carbon energy, photons, and quantum technologies. In April 2018, South Korea's Ministry of Science, ICT and Future Planning also implemented the Innovative Growth Engine Promotion Plan, which aims to tackle the future Industry 4.0 challenges by focusing on big data, 5G network, AI, autonomous vehicles, unmanned vehicles, smart city, virtual and augmented reality, robots, new drug development, advanced semiconductor, materials, and renewable energy. In addition to Japan and South Korea, the European Commission also launched the Re-finding Industry-Defining Innovation in April 2018, providing a list of technologies (e.g., advanced manufacturing, materials and nanotechnology, life science, micro/nanophotonics, and photonics) as the key direction for Horizon Europe, the 9^{th} Framework Programme.

In addition to the general science and technology R&D roadmap as mentioned above, various countries are also committed to planning the development of single technological domains. For instance, more than 20 countries worldwide have proposed AI development strategies and action plans, with the hope of seizing opportunities from potential breakthroughs in AI. Generally, the United States has its various state departments propose theme-based science and technology projects rather than adopting general national-level science and technology development plans or white papers. For example, in November 2017, the National Science Foundation (NSF) announced the 10 Big Ideas for future science and technology research projects: Harnessing the Data Revolution, Future of Work, Navigating the New Artic, Windows on the Universe, Quantum Leap, Understanding the Rules of Life, Mid-Scale Research Infrastructure, NSF 2026, Growing Convergence Research, and NSF INCLUDES (NSF Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science). An overview of science and technology inputs and R&D resource allocations in various countries shows that intelligent, health, and sustainability related technologies are typically included in the list of future plans by science and technology departments. These directions align perfectly with the UN's SDGs. The development of emerging technologies resonates with humans' common values and goals. Taiwan should follow this trend, meet the requirements of local society and industrial development, and choose suitable science and technology projects, and actively commit to R&D initiatives.

2. Taiwan's Capacity and Strengths in Scientific Research

This section is based on the patent situations of academic papers in Taiwan and overseas and the United States Patent and Trademark Office (USPTO) to analyze the development trends and international competitiveness of various academic and technical fields in Taiwan and to identify areas with advantages and potential.

Regarding the trends in the publication of academic papers, the United States, China, and United Kingdom are the three countries with the highest number of journal publications between 2014 and 2017. Taiwan was ranked 21st in the world and 5th in Asia. Although the number of Taiwanese-authored papers has declined slightly in recent years, each paper has been cited 5.08 times between 2010 and 2014 and 5.75 times between 2013 and 2017 according to the Science Citation Index (SCI), with the total number of citations maintaining the 19th place in the world.

An overview of Taiwan's competitiveness in academic papers between 2013 and 2017 (see Figure 4-1; red dashed line represents global average) reveals that Taiwan was concentrated on the areas of computer science, engineering, economics and business, material science, space science, physics, and clinical medicine, and exhibited high impact factor performance in the areas of space science, physics, agricultural science, botany and zoology, pharmacology and toxicology, and material science. Agricultural science and botany and zoology exhibited high impact factor but low concentration, indicating that these subjects are characterized by low quantity and high quality. By contrast, space science, computer science, engineering, material science, and physics exhibited significant advantage in terms of impact factor and field concentration, implying that Taiwan is most competitive in these academic fields.

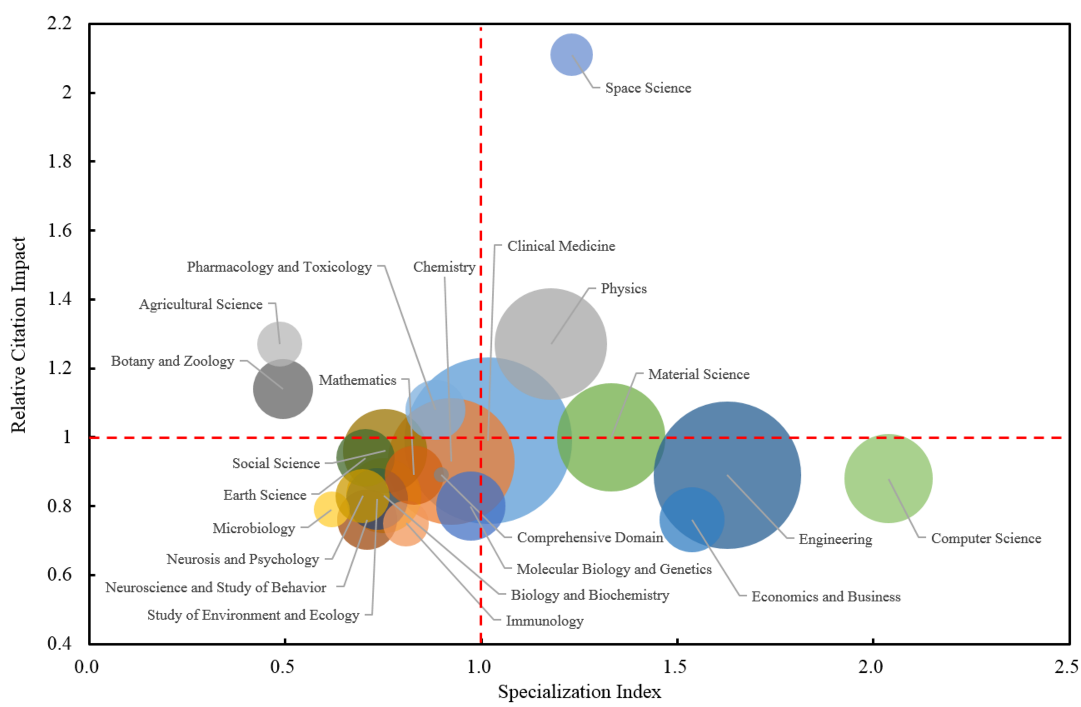

Figure 4-1. Analysis of Taiwan's academic competitiveness

Data Source: InCites (2018/09), organized by STPI.

Regarding international patent publication, Taiwan's number of patents approved by the USPTO ranked 5th in the world in recent years but dropped to 6th in 2017. The number of approved patients dropped from 11,333 patents in 2014 to 11,161 patents in 2017. Regarding competitiveness in technical fields, the 34 sub-technical fields defined by the World Intellectual Property Organization (WIPO) were used to calculate field concentration and relative impact factor to analyze Taiwan's patent competitiveness in various fields of study (see Figure 4-2; red dashed line represents global average). The results show that Taiwan's patents approved by the USPTO were concentrated on semiconductors, micro-structure and nano-technology, optics, basic communication processes, power equipment, and electrical machinery, apparatus, energy. Specifically, semiconductors and optics exhibited high concentration and relative impact factor on par with global average. Taiwan has fewer patents in public engineering; however, the impact factor of this field was higher, suggesting that civil engineering was characterized by low quantity and high quality. Electrical machinery, apparatus, energy, and mechanical elements exhibited high concentration and high impact factor. Thus, Taiwan was most competitive in these technical fields.

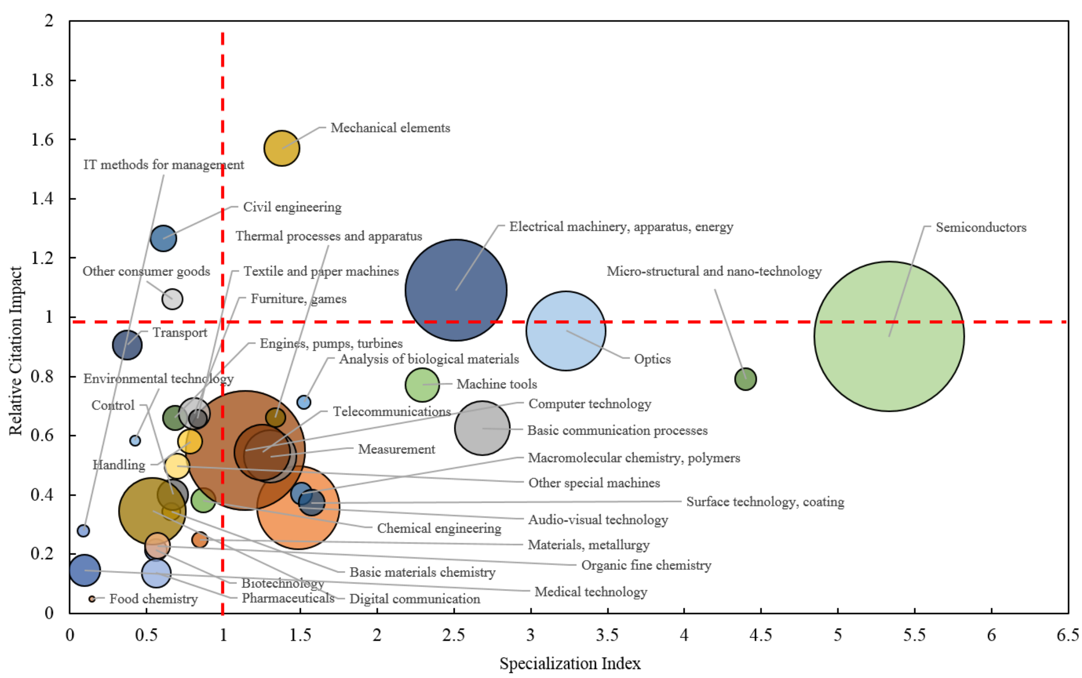

Figure 4-2. Analysis of Taiwan's patent competitiveness

Data Source: USPTO (2018), organized by STPI.

Analysis of Taiwan's academic and technical competitiveness reveals that Taiwan exhibits competitive advantage in technology and potential in numerous disciplines. In the contemporary era wherein global science and technology is developing rapidly, global competitions in scientific research and industries are intensifying, and the turnover rate of global scientific researchers is increasing, Taiwan should concentrate its resources on niche technical fields that have potential, are a strength of Taiwan, and meet future requirements, in order to establish a friendly scientific research environment, consolidate the country's human capitals, foster its scientific research foundation and capacity through industry-academic-research collaboration and international cooperation, and convert scientific research seeds that contribute to the global society and benefit human wellbeing, into real-life applications to enhance Taiwan's scientific research capacity and global influence.

3. Taiwan's Future Scientific Research Plans

This Roadmap examines key issues concerning various aspects of Taiwan, assesses technical requirements and contemplates the challenges and opportunities facing Taiwanese industries and society, summarizes the current trends and breakthroughs related to global science and technology development as well as the research capacity of industries, academic institutions, and research institutes in Taiwan, filters a list of key R&D projects that Taiwan is likely to invest in in the future, and formulates Taiwan's future R&D plans in the four pillars of intelligence, health, sustainability, and scientific exploration. Figure 4-3 summarizes the strategies and scientific research plans for promoting the socioeconomic development of Taiwan. Challenges and opportunities, implementation direction, and the focus of science and technology plans in terms of the four pillars are explained below.

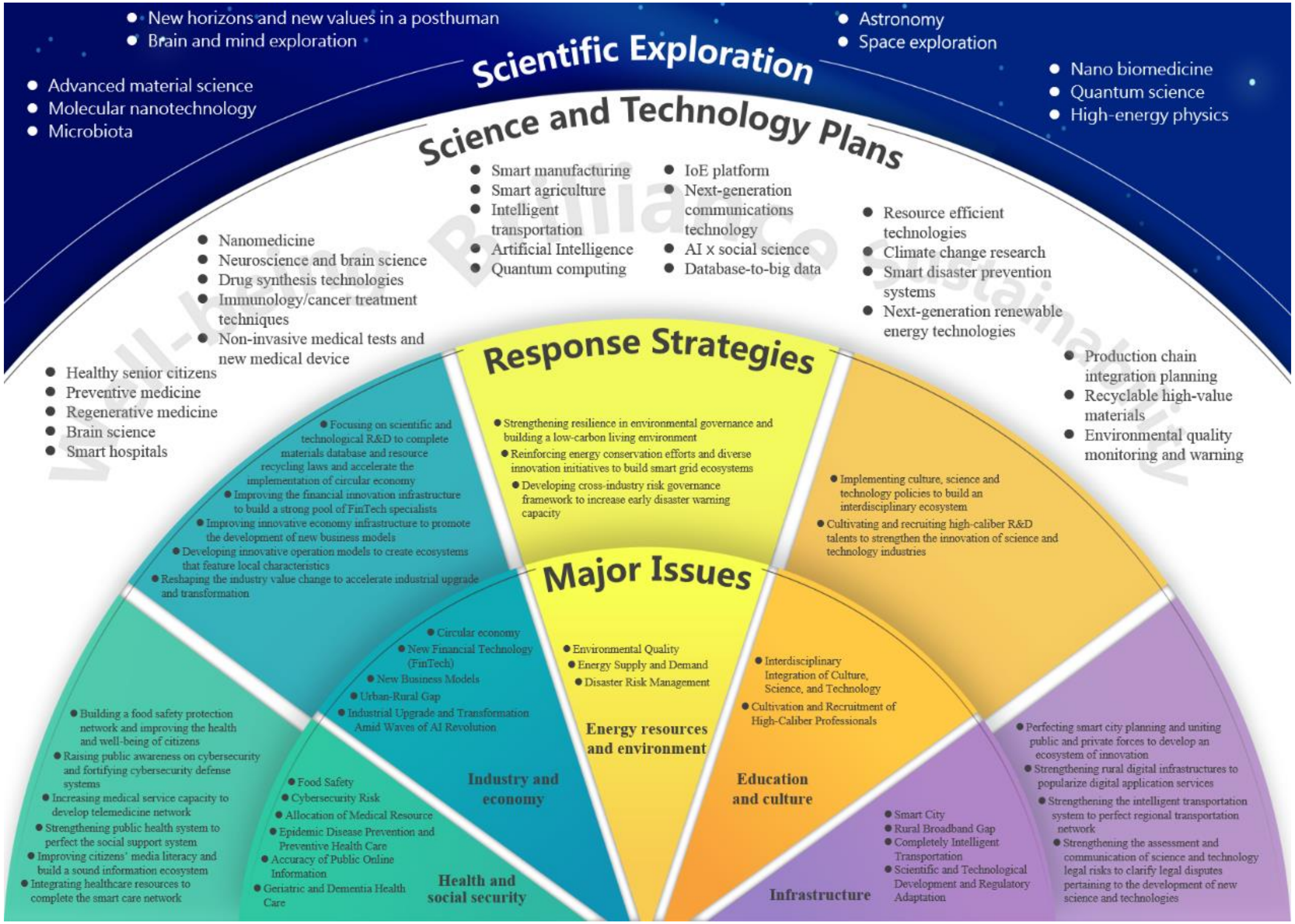

Figure 4-3. The strategies and scientific research plans for promoting the socioeconomic development of Taiwan

(1) Brilliance

A. Challenges and Opportunities

A future world of Internet of Everything (IoE) may become a breeding ground for hackers, which will engender severe cybersecurity problems. Smart robots will penetrate the workforce and replace labor workers. Social stability and lifelong learning will become a topic of focus for everyone in the future. However, digital revolution and smart automation will also create new opportunities for industries, invigorate economic activities, increase the requirements for ICT applications, and facilitate the growth of ICT industries.

B. Implementation Direction

A smart city is a society that incorporates digital and physical networks and applies advanced technologies to solving social and economic problems. In science and technology, we plan to focus on hardware technologies, software and algorithms, and social science and invest in projects involving smart manufacturing, IoE platform, next-generation communications technology, smart agriculture, intelligent transportation, quantum computing, AI, database (DB)-to-big data (BD), and AI×social science.

C. Focus of Science and Technology Plans

(A) Developing hardware technologies for a smart city: Smart manufacturing, IoE platform, next-generation communications technology, smart agriculture, intelligent transportation

Smart manufacturing refers to the use of digital technologies (e.g., AI, sensors, cloud, robots, cyber-physical system [CPS], additive manufacturing, and IoT) and integration with hardware and software applications to introduce intelligent designs and innovation capacity into manufacturing systems. For example, 3D printing uses computers to convert 3D digital models into cross-sectional patterns comprising hundreds and thousands of layers. Materials are added together layer by layer, converting a virtual file into a physical model. This “additive” manufacturing method can realize digital manufacturing, laying a foundation for developing next-generation manufacturing technologies.

An IoE platform includes communication, sensing, cloud, and cybersecurity technologies. Key technologies (e.g., B5G or 6G mobile communications, which can provide super high-speed

Internet) should focus on not only applied technologies but also fundamental theories (e.g., antenna propagation, signal processing and coding, molecular communication, and other next-generation communication technologies) to form a preliminary plan for building a complete technological system. Moreover, in situations where objects are interconnected and operated in large quantities, cybersecurity will become critical, particularly in simple IoT devices. Hence, developing high-speed, secure IoT platforms will be an inevitable topic in the future.

Smart agriculture is an integral part of future smart applications, which involves the use of intelligent technologies to develop innovative smart farming machines. By developing smart auxiliary machine tools that feature he advantages of farm machineries and monitoring equipment, using advanced plant breeding and pest control technologies, and conducting R&D on key technologies for the reuse of farm wastes and water resources, environmental optimization, and processing, we aim to make agricultural practices smarter and upgrade the agricultural environment.

Transportation network is a city's circulatory system. Intelligent transportation can effectively improve a city's traffic and logistic performance, reduce traffic accidents, and increase traffic management efficiency. Smart transportation is the solution to conserving energy, reducing carbon emission, and sustaining the urban environment in response to future urban problems such as overpopulation and traffic congestion.

(B) Shaping the inner core of a smart society: AI and quantum computing

Thanks to deep learning algorithms, AI has been successfully applied in medicine, transportation, retail banking, cybersecurity, and smart manufacturing. The future trends of AI technology include machine learning, deep learning, data mining, robotics, computer vision, natural language processing, gaming, and neural network chips.

Quantum computers feature entanglement, superposition, and quantum uncertainty characteristics. Quantum computers have a powerful parallel computing capability, making them capable of controlling the recording and computing of atom states, and expressing and processing multiple states. In addition, quantum mechanics also provide safe quantum communication mechanisms to ensure secure data transmission. In future, quantum computing will use high-performing computational models to implement computer, ICT, sensing, and smart interdisciplinary applications, thereby instigating a new wave of information revolution.

(C) Social impact: Database (DB)-to-big data (BD), AI×social science

We plan to establish interdisciplinary research projects, collect empirical data on the education, society, and bioethics of Taiwan, and build a research data sharing platform. The database will be composed of social change investigations, election and democracy surveys, empirical study of Taiwanese laws, childhood development surveys, and data of ministerial departments. We will use these databases and platforms to explore the social risks of different domains, including ethics and paradigms of a digital era, FinTech, autonomous vehicles, and health care.

(2) Well-being

A. Challenges and Opportunities

The advancement of healthcare quality and medical technologies has prolonged the average life expectancy of Taiwanese citizens. As a result, Taiwan will become a super-aged society by 2026 (20.6%). The continuous increase in aging population will considerably increase people's demand for healthcare services, further cumulating the financial burden of Taiwan's government and ordinary households.

Due to the impact of population aging and declining birth rate, medical institutions in Taiwan will eventually run out of human resources to support the dramatic increase in elderly patients and people who require healthcare services. Therefore, the healthcare and industrial sectors are facing major challenges and opportunities in achieving breakthroughs in life science and clinical medical technologies, integrating intelligent and ICT technologies to improve healthcare infrastructures, and essentially enhancing the effectiveness of healthcare services to improve people's quality of life.

B. Implementation Direction

Our general plan will cover a comprehensive range of basic, application, and service topics. Specifically, advanced medical technology development projects will involve nanomedicine, neuroscience and brain science, precision medicine, regenerative medicine, and preventive medicine. Clinical, new drug, and new medical device research will involve immunology/cancer treatment techniques, non-invasive medical tests and new medical device, and drug synthesis technologies. Finally, we will promote the construction of user-oriented smart hospitals and social science research on the health of senior citizens.

C. Focus of Science and Technology Plans

(A) Development of advanced medical technology: Nanomedicine, neuroscience and brain science, precision medicine, regenerative medicine, and preventive medicine

In an aging society, brain and neurological disorders (e.g., Alzheimer’s and Parkinson’s disease) and neurodegenerative diseases have become major social/health concerns. The rehabilitation and care needs arising from these types of pathological changes will exhaust a large amount of resources and manpower for families and societies. Related research topics include the study of neural development and behavior, neurodegeneration, hearing and speech impairment, stroke, drug abuse, anesthesia, and neural therapy (including neuropharmacology and stem cells).

The combination of nanotechnology and biomedicine is called nanomedicine. Topics of discussion in nanomedicine include the development of nanoscale drugs, nanoscale drug carriers, smart medical micro-robots, and medical imaging technologies. In future, we will place emphasis on precision prevention and early detection technologies, including the development of liquid biopsy and biomarker analytical techniques, microvolume molecular cellular tissue imaging and detection analysis methods, as well as high-accuracy and high-precision biomedical sensing technologies.

Regenerative medicine can be applied to tissue organ loss or functional deterioration of human organs caused by diseases, aging, and trauma. Stem cells can potentially develop into different types of cells during the growth process, becoming a key research topic in the field of regenerative medicine. Research topics relating to regenerative medicine include repairing heart function, cell therapy for neurodegenerative diseases, and organ regeneration.

Preventive medicine is a branch of medicine aimed at preventing the occurrence of human disease and maintaining the health and wellbeing of individuals. The research scope in preventive medicine includes studies of environmental health, food safety, epidemiology, health statistics, toxicology, and medical genetics. Intestinal health, nutrition, and newborn critical congenital heart disease screening program are also crucial research topics relating to preventive medicine.

(B) Clinical, new drug, and new medical device research:

Immunology/cancer treatment techniques, non-invasive medical tests and new medical device, and drug synthesis technologies

The study of immunology involves investigating the defense response after a host is infected by a pathogen or the resulting allergic reaction and autoimmune mechanisms. Research topics in the study of immunology include cancer therapy, molecular immune regulation of infection and immune related diseases, allergy, inflammation and defense mechanism, the mechanism of action of pathogenesis and drug resistance, disease diagnosis and treatment, drug design and screening, and antibody and vaccine development.

Medical testing methods include a wide range of clinical testing techniques such as biochemical test, serologic and immunologic tests, microbial test, cancer screening, metabolism test, and blood test. Researchers can use novel medical testing techniques to identify molecular targeted drugs that can be used in clinical and therapeutic testing. Subsequent research target will focus on the development of non-invasive medical testing methods, including immunological agents, enzyme analysis, nucleic acid analysis, and biochip.

Regarding medical devices and medical assistive tools, we intend to develop new materials, minimally invasive machineries, functional artificial tissue and organs, and medical applications integrated in the field of medical engineering; strengthen academic research and applications, promote user-oriented product designs, and create medical devices of commercial value.

Regarding new drug development, we plan to develop natural plant medicinal applications for use in geriatric disease treatment and health care, which is currently trending. Taiwanese health authorities have established years of experience in clinically using traditional Chinese medicine, and these experiences are the foundation for developing novel Chinese medicine. Using nanotechnology to design novel small-molecule drugs and targeted drugs is also the direction of future new drug development.

(C) Creating the applications needed in Taiwan: Smart hospitals and healthy senior citizens

Smart hospitals will integrate ICT and intelligent technologies in information systems, smart hospital wards, clinics, operating theater, nursing stations, and emergency rooms to build the future smart healthcare systems to meet the healthcare needs of citizens.

By promoting the Innovation and Policy Research center that values group health and sustainable environment, we will implement the New Reciprocal Era: Community Practice of Time Bank project to build a healthy geriatric society, where senior citizens participate in community and social interaction activities to stay healthy and energetic. We will conduct research on issues and design action plans to highlight regional characteristics and create a quality community living environment.

(3) Sustainability

A. Challenges and Opportunities

Taiwan typically imports minerals and energy fuels, demonstrating an energy import dependency of 98%. In recent years, the fluctuation of energy and raw material prices has increased the risks of industrial operations and national security; therefore, increasing the overall resource recycling and reuse rate, developing a circular economy model, and elevating the country's energy autonomy, and simultaneously solving power supply stability problems are crucial. In addition, global warming has resulted in increasingly frequent extreme climate conditions such as super typhoons and torrential rain. According to Germanwatch's 2018 Global Climate Risk Index, Taiwan's climate risk was ranked 7th in the world, suggesting that Taiwan must strengthen its environmental and facility resilience, keep abreast of climate data and disaster-prone areas, and implement adaptive strategies to control climate disaster threats. Regarding environmental quality, because of Taiwan's geographical location and topographic factors, air pollution in Taiwan is created from domestic sources and blown over from China. Air pollution severely endangers the health of citizens. Effective countermeasures must be formulated as soon as possible.

B. Implementation Direction

To transform Taiwan into a sustainable environment, the government should promote the recycling and reuse of energy resources through scientific and technological R&D and planning and construct a circular economy system. Meanwhile, safe living environment should be developed by making use of natural resources, developing local alternative energy, energy storage devices, and smart power distribution systems to realize a low-carbon society, and using environmental monitoring and AI technologies to develop systems that monitor pollution and issue early warning signals for disaster-prone areas. Science and technology projects are focused on the following: recyclable high-value materials, resource efficient technologies, production chain integration planning, alternative energy, smart grids, energy storage devices, advanced energy conservation technologies, smart disaster prevention systems, environmental quality monitoring and warning, and climate change research.

C. Focus of Science and Technology Plans

(A) Promoting resource recycling and reuse: Recyclable high-value materials, resource efficient technologies, production chain integration planning

Regarding recyclable high-value material technologies, we should develop high-value new materials, environmentally friendly low-carbon new materials, and key materials and technologies for circular processes; strengthen the development of technologies that convert recycled wastes into high-value products and encourage public, private, academic, and research sectors to promote the transformation of material industries into high-value low-carbon industries. The implementation direction for converting wastes into resources includes converting organic and inorganic wastes into resources and recycling electronic wastes to promote the recycling and reuse of energy resources. Regarding production chain integration planning, we should promote industry co-existence and resource integration to achieve zero waste output. In response to the future tightening of energy resource supply, we should combine innovation business models with systematic planning, and incorporate new technological applications to encourage industrial energy resource recycling and reuse. We can also extend to cities or regions for resource integration planning, gradually move away from the conventional practice of "waste management" and slowly adopt "resource recycling and circular economy" model to produce, transfer, and use energy resources more efficiently, thereby realizing the policy goals of a circular economy system.

(B) Developing efficient, low-carbon energy: Alternative energy, smart grids, energy storage devices, advanced energy conservation technologies

Taiwan is not energy self-sufficient and adopts isolated island microgrid systems using centralized power supply, which poses a major challenge to ensuring energy safety and stable power supply. Hence, the development of alternative energy sources, smart grids, as well as energy storage and advanced energy conservation technologies is urgently required to achieve Taiwan's energy transformation goals and realize its sustainable development vision. The direction for developing alternative energy technologies includes developing solar battery and module technologies with high price-performance ratio, implementing domestic offshore wind power, developing non-food biofuels/product technologies, and considering whether the manufactured products are sustainable and environmentally friendly. When a high percentage of renewable energy is introduced into electric grids, energy input must be regulated by using smart grids and grid energy storage systems with dynamic response and scheduling functions to effectively increase power supply stability. However, onsite verification must be performed on power suppliers or users to facilitate increasing the use of green energy, thereby achieving energy conservation and carbon reduction. Furthermore, the growth in demand for electric vehicles is also a key factor driving the advancement of energy storage technologies. Developing advanced energy-saving technologies can reduce energy consumption. Using smart regulation technologies coupled with time-of-use electricity saving measures can effectively transfer peak power load, reduce overall power investment cost, and ensure stable power supply. We should therefore actively develop core subordinate patients for energy-saving technologies and establish innovation business models to bolster the international competitiveness of Taiwan's industry chain.

(C) Building a resilient home that is protected against disasters and pollution: Smart disaster prevention systems, environmental quality monitoring and warning, and climate change research

Because of Taiwan's complex topography, weather disaster prevention technologies developed in other countries cannot be used directly in Taiwan. Local information and real-life experience must be used to develop weather disaster prevention technologies for Taiwan. Data assimilation methods can be employed to extend the monitoring functions of weather radars to real-time or short-term weather forecasting. Concurrently, deep learning, computer vision, and other AI technologies can be applied in combination with big data analytics to establish an environmental monitoring and real-time information analysis and prediction model to strengthen existing disaster prevention and early warning monitoring systems. Regarding air quality monitoring, we should develop high-resolution air quality monitoring, information transfer, and forecasting models, thereby using scientific data to help the government to formulate air quality management and pollution reduction strategies. We should also develop air quality deterioration warning systems that use machine learning and collect and analyze massive volumes of data to ascertain pollutant sources and route of dispersion and construct precise environmental monitoring and warning networks.

Tackling climate change challenges is crucial for Taiwan, a country that is extremely vulnerable to climate risk. In future, we should refine Taiwan's climate change simulation and estimation capability and develop local climate simulation systems, in hopes of becoming one of the few countries in the world capable of performing long-term climate change simulation and estimation. Moreover, the simulation systems can be used to assess the potential impact of climate change on Taiwan, providing a basis for planning and adjusting climate change adaptive strategies.

(4) Scientific Exploration

A. Challenges and Opportunities

Science and technology are advancing at an incredible speed, while global industry and technology maps are changing rapidly. Countries around the world are competing fiercely with each other to develop the most cutting-edge core technologies and vie for competitive advantages. Taiwan has devoted years of commitment in the fields of semiconductor and ICT, gaining prominence in the world. Taiwan has also extended its global presence in basic science domain and as a result, we have built a pool of outstanding scientific researchers and developed a strong capacity in the R&D of science and technology. However, to prepare for the fierce competitions with international industries, scientific research communities, and talented professionals in the future, Taiwan urgently needs to strengthen its capacity in basic scientific research, build a friendly scientific research environment, foster its human capitals, and recreate a competitive niche in scientific research. Scientific exploratory research serves to accumulate knowledge for the benefit of future generations and involves high risk and high uncertainty. If the management of our scientific exploration overly emphasizes economic benefits and goal performance, the long-term benefits of scientific explorations such as knowledge accumulation, technological advancement, and talent cultivation will be overlooked. Therefore, we basic research should be considered a country’s strategic resource that must be accumulated for long periods in order to perpetually stimulate innovation and continuously improve the country’s innovation competitiveness.

B. Implementation Direction

To strengthen the scientific exploration capacity of Taiwan, we should continuously support basic scientific research, encourage participation in international collaborations, and leverage the research capacity of developed countries to stay ahead of cutting-edge development, increase the international visibility of Taiwan’s scientific research outcomes, and recreate competitive niche in scientific research. Scientific research can follow four principles: exploring the mysteries of nature and the universe, discovering the endless capacity of the microcosm, understanding the small universe of human life, and promoting dialogue between science and humanity. Research projects include: High-energy physics, astronomy, space exploration, quantum science, molecular nanotechnology, advanced material science, nano biomedicine, microbiota, brain and mind exploration, and new horizons and new values in a post-human era.

C. Focus of Science and Technology Plans

(A) Exploring the mysteries of nature and the universe: High-energy physics, astronomy, space exploration

Regarding high-energy physics research, research teams in Taiwan have actively participated in international research projects, including the Large Hadron Collider (LHC) Compact Muon Solenoid (CMS) project in 2002, which was hosted by the Conseil Européen pour la Recherche Nucléaire (CERN). In 2013, the LHC team won the Nobel physics prize for discovering the Higgs Boson. Taiwan's high-energy experimental research team is capable of designing and producing cutting-edge components. In future, the team can incorporate high-energy and particle astrophysics applications and seek to cooperate with schools and industries that specialize in electromechanical systems, electronics, and computers, thereby enhancing Taiwan's cutting-edge research capability.

Regarding astrophysics, the discovery of gravitational wave by the Laser Interferometer Gravitational-Wave Observatory (LIGO) in 2015 established a historical milestone for the study of astrophysics and also gave birth to the winner of the Nobel physics price in 2017. Academic communities in Taiwan have joined the LIGO and partook in the Kamioka Gravitational Wave Detector (KAGRA) experiment, contributing to the coating and calibration of interferometer. Taiwan also made its presence in Atacama Large Millimeter/Submillimeter Array (ALMA) project, the largest ground-based astronomical telescope in history. In future, Taiwanese research teams will collaborate with international research communities to conduct multimedia astronomical observation by using gravitational waves and electromagnetic waves of different bands to obtain a more comprehensive understanding of information transmitted from the stars, galaxies, and the universe. Regarding space exploration, Formosat-5, which is an optical remote-sensing satellite made in Taiwan, was launched in August 2017 and successfully acquired global ionosphere maps and remote sensing images. This success is a testament to Taiwan's ability to independently research and produce high-resolution remote-sensing satellite. Taiwan has the potential to develop space technologies. In future, we should tap into the R&D capacities of international communities and integrate the research capabilities of industrial and academic sectors to actively develop key autonomous space technologies and accumulate R&D experiences and human capitals for the development of space technologies.

(B) Discovering the endless capacity of the microcosm: Quantum science, molecular nanotechnology, advanced material science

As the post Moore's law era and development of AI further increase the demand for parallel computing, developing quantum applications plays an integral role in meeting this increased demand. Development focus includes quantum control, quantum information (quantum computing and quantum communication), quantum sensors, and quantum components. Taiwan should make use of its strengths in ICT development and actively integrate the research capacity and resources of various fields to launch a series of collaborative research on the fundamental theory of quantum, quantum memory, semiconductor/superconductive quantum bit, tangled photons, and other relevant fields and develop prospective quantum science applications. Miniaturization and additive manufacturing of materials and components are also crucial for producing smaller chips that can process large volumes of data with maximum efficiency. Molecular nanotechnology predicts the possibility of realizing a nanoscale factory and molecular manufacturing, which enable precision and durable products to be produced at low cost and allow nanomedicine to be incorporated to treat a wider range of diseases. The development of advanced materials is key to advancing science, refining technologies, and developing industries. In particular, smart biomimetic materials, advanced metal materials, cutting-edge crystalline materials and 2D/3D materials are all key areas of novel material research. Multiscale material simulation and design systems can be developed by integrating AI in quantum computing to establish materials genome initiative (MGI) platforms for increasing the efficiency and precision of materials R&D.

(C) Understanding the small universe of human life: Nano biomedicine, microbiota, brain and mind exploration

The field of nano biomedicine has been cultivated for many years in Taiwan. In future, Taiwan will focus its implementation efforts on the development of nano biomedicine technologies and key technologies for early disease detection and treatment, such as in vitro liquid biopsy specimens, high-throughput biochip detection, microvolume molecular cellular tissue imaging and cutting-edge detection technology, high-accuracy and high-precision biomedical sensing technology, and new small-molecule drugs and carrier synthesis technologies. The end goal is to promote interdisciplinary cooperation in areas of medical imaging, biomedical sensing, precision instruments, and nanotechnology.

Microbiota is strongly related to human's immune system, metabolism, nerve system, and development. Governments worldwide have injected monetary investment to support large-scale microbiota research projects. Taiwan must also establish a local microbiota (e.g., human gastrointestinal microbiota) database exclusively for people of Taiwan. In future, the government should focus on developing microbiota biomarkers or technologies for disease diagnosis and prevention, conducting research to develop probiotic drugs, exploring the effect of microbiota on the efficacy of existing drugs and treatments (e.g., chemotherapy and immunotherapy), and using AI to analyze big data to identify the associations between microbiota and disease development, thereby providing reference for the diagnosis, prevention, and treatment of all types of diseases. Currently, Taiwan's aging society is profoundly affected by the vast amount of social resources expended to address problems resulting from neuropathy/neurodegeneration and mental disorders. Therefore, we must explore how our brain is associated without our mind in order to develop relevant applications. In research on brain and mind science, the association between complex nerve systems and the mind is explored to verify theoretical assumptions. Brain and mind research has the potential for diverse translation. Relevant authorities in Taiwan should integrate the research capacity of different disciplines and combine cognitive neuroscience with Taiwan's social science studies to actively promote neuroimaging and mind science research.

(D) Promoting dialogue between science and humanity: New horizons and new values in a post-human era

Francis Fukuyama, a Japanese American scholar, wrote a book called *Our Posthuman Future*, where he discusses how biotechnologies such as brain and behavioral science, neuropathy and manipulation, extension of life, and genetic engineering, will steer humans toward a posthuman era. If ethical norms are not established, the posthuman future will compromise the foundation on which human society, economy and culture are built. Given the dramatic development of AI and robots, the physicist Professor Stephen William Hawking also proposed the huge potential benefits of AI for humans. However, he stressed that AI should work in accordance with humans' will; otherwise, the resulting risks will be uncontrollable. Facing the profound changes in time and civilization brought about by science and technology, we should take into account ethical issues as science progresses, and promote dialogue between science and humanity, so that scientific development can reconcile with the development of human society to discover new horizons and new values in the posthuman era.

Chapter 5. Small Economy, Smart Strategy

According to the 2018 WEF Global Competitiveness Report, Taiwan's overall competitiveness ranked 13th out of 140 countries. Taiwan ranked 4th in the world in innovation capability, standing alongside Germany, the United States, and Switzerland as one of the world's four Super Innovators. This achievement shows that Taiwan is a small country; however, the country is able to gain global prominence as long as it makes good use of its limited resources, selects and focuses on the correct science and technology projects, and builds a sound innovation ecosystem.

This Taiwan Science and Technology Roadmap (2019-2022) upholds a people-centered core value to prepare Taiwan for its future challenges. By providing an overview and analysis of international trends and conducting inventory of key issues in Taiwan, we propose a number of response strategies and science and technology plans in the dimensions of "health and society safety," "industry and economy," "energy resources and environment," "education and culture," and "infrastructure" to help Taiwan to establish competitive advantages and keep its position as the world's leading innovator.

To realize this vision, our science and technology development will adhere to the following four guiding principles (see Figure 5-1):

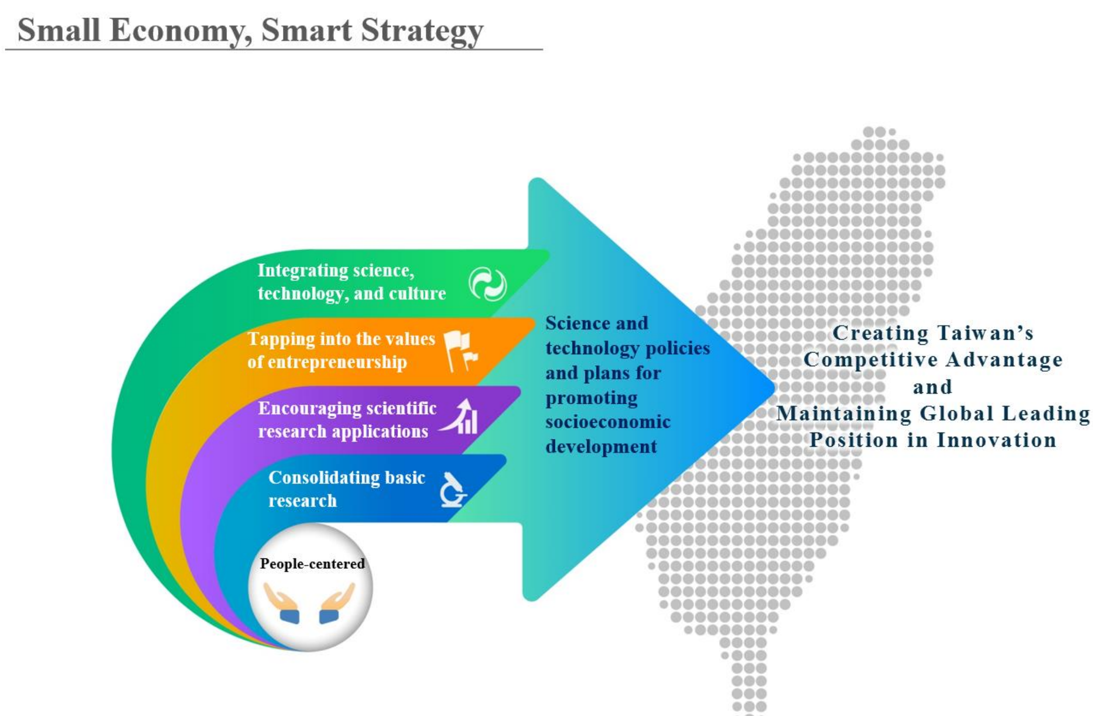

Figure 5-1. The guiding principles of the Taiwan Science and Technology Roadmap (2019-2022)

(1) Consolidating basic research

The foremost principle of a national science and technology development strategy is consolidating basic research. Humans explore the unknown out of curiosity. The ultimate breakthrough in key technologies or significant scientific discovery is a form of basic research. Nevertheless, only by igniting researchers' passion for scientific exploration and encouraging researchers to think without a box, pursue knowledge, seek the truth, and forge ahead without fearing for failure and challenges, can we continue to stay ahead of scientific progress, build a strong base for basic research, and achieve true scientific breakthroughs and innovations. Therefore, a national science and technology development strategy must prioritize injecting resources in basic research and not only maintain the growth of research funding, but also adopt a new way of thinking about innovation policies to break free from the traditional frameworks of science and technology policies and resource distribution, establish budget protection systems, and consolidate Taiwan's basic research capacity.

(2) Encouraging scientific research applications

Science knowledge is the shared asset of human society. Scientific research applications are also the driver of perpetual advancement and continuous evolution. The value of science stems from the practical application of knowledge to contribute to social progress and economic development. Exploration and application complement each other. Scientific exploration continuously creates revolutionary research outcomes and discovers promising research topics according to societal needs. Therefore, the significance of developing science and technology lies not only in how to explore problems and build knowledge, but also in applying knowledge to promote and address the complex and diverse social development needs, so that every basic scientific research can become the basis of practical applications and create opportunities and the value of serving society through science and technology.

(3) Tapping into the values of entrepreneurship

One might feel frustrated in the process of scientific research. However, science is all about making attempts and experiencing failure. Only by tolerating failure and persisting in innovation can researchers achieve success. Particularly, effective use of limited resources, maximizing value, challenging the unknown without fearing for failure, and showing perseverance are all the core characteristics of entrepreneurship. Hence, a national science and technology development strategy is responsible for and obligated to guide education and research systems to foster more entrepreneurial talents who are brave enough to embrace challenges. Compensating for the inherent disadvantages (limited resources) of s small country, engaging in open innovation, leveraging outside resources, and forging ties with international communities to identify the key advantages of leading the world will be the crucial elements of science and technology.

(4) Integrating science, technology, and culture

Under a people-centered core value, science and technology development should be accompanied by compassion for humanity. Science and technology are not merely a tool for promoting cultural preservation and revitalization. Advancement in science and technology is the driver prompting changes in civilization and cultural development. Culture is the sum total of ways of living built up by a group of human beings. Hence, a national science and technology development strategy should infuse imaginations about future way of living, strengthen soft innovation, integrate human elements into new technologies, and increase the cultural contents of the future society of science and technology so that science and technology are transformed into not only a tool but also a field that touches people's heart and nurtures cultural and humanitarian values.

Following these four guiding principles, the Taiwan Science and Technology Roadmap (2019-2022) aims to promote industrial transformation through science, technology and innovation, boost Taiwan's economic development, fulfill the requirements for social development, demonstrate the economic and social benefits of science and technology, create competitive advantages for Taiwan, sustain Taiwan's position as the world's leading innovator, and build a nation through science and technology.

Taiwan Science and Technology Roadmap (2019-2022)
(Short Version)

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